AN ANALYSIS OF AIR MOBILITY EXPRESS REQUIREMENTS OPERATING WITHIN A LEAN LOGISTICS WARTIME ENVIRONMENT

THESIS

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Jennifer A. Bollinger

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Glossary

Airlift Deployment Analysis System (ADANS)

The Airlift Deployment Analysis System is an Air Mobility Command unique automation system which provides interactive deployment scheduling, scheduling for deliberate planning, wartime and contingency planning, exercise deployment and redeployment planning, peacetime scheduling, and airlift efficiency analysis.

Automated Weapon System Master Plan (AWSMP)

The Automated Weapon System Master Plan Module aggregates and integrates weapon system performance assessment, logistics support and improvement program, and financial management data to support planning and decision-making (HQ AFMC/SXMW, 1991: 7).

Airlift Clearance Authority (ACA)

The Airlift Clearance Authority is the activity that controls the entry of traffic in the airlift system (AFI 24-201, 1994: 16)

Aerial Port of Debarkation (APOD)

The Aerial Port of Debarkation is the geographic point at which cargo or personnel are discharged (AFI 24-201, 1994: 18)

Aerial Port of Embarkation (APOE)

The Aerial Port of Embarkation is the geographic point in a routing scheme from which cargo or personnel depart (AFI 24-201, 1994: 18).

Aircraft Availability

Aircraft availability is a measure of a flying unit's percentage of fully mission capable aircraft resulting from the total number of expected backorders for that unit. Aircraft availability directly results from the projected pipeline flow of spares into the deployed theater of operations (Isaacson and Boren, 1993: 33).

Air Lines of Communication (ALOC)

Air Lines of Communication is similar to COMALOC but uses a military APOE (USTRANSCOM, 1995: 9).

Air Mobility Express (AMX)

Air Mobility Express is the military adaptation of commercial overnight delivery that consists of (1) express carriers' CONUS infrastructure, (2) AMC airlift (organic or CRAF), and (3) the battlefield distribution system (BDS) for express shipments. For AMX-C, CRAF carriers provide DoD not only the use of aircraft, but their integrated CONUS express infrastructure. Express carriers' distribution structures will be used to pick-up/deliver cargo to/from their hubs where the carrier's personnel will load, off-load,

and service AMC airlift missions. AMC will provide daily round trip direct service between the express carriers' CONUS hubs and the designated APOD(s) in the theater of operations. For AMX-M, military APOE's will be used instead of commercial hubs. The theater commander will establish a distribution system that provides next day delivery of critical cargo (HQ AFMC Slide Package, 1995).

AMX (M)

Military hub version of AMX.

AMX (C)

Commercial hub version of AMX.

Area of Responsibility (AOR)

The area of responsibility is the geographical area associated with a combatant command within which a combatant commander has authority to plan and conduct operations (Joint Pub 4.0, 1995: GL-3).

Battlefield Distribution System (BDS)

Battlefield Distribution System is a theater-established rapid intra-theater distribution system, designed by the US Army's CASCOM, to lash-up with AMX. Theater transportation (airlift or ground) assets await the arrival of AMX at the theater distribution hub (similar to the CONUS hub) and after a fast sort, cargo is delivered direct to forward units (SLMC).

Centralized Intermediate Repair Facility (CIRF)

A Centralized Intermediate Repair Facility is an echelon between bases and depots that provide logistics support (repair and supply) to one or more bases (Isaacson and others, 1988: xv).

Channel Airlift

Common-user airlift service provided on a scheduled basis between two points. There are two types of channel airlift: a requirements channel serves two or more points on a scheduled basis depending upon the volume of traffic and a frequency channel is timed based and serves two or more points at regular intervals (Joint Pub 4-01, 1995: GL-7).

Commercial Air Lines of Communication (COMALC)

Commercial Air Lines of Communication is a DLA distribution system that uses two consolidation control points (New Cumberland and Sharpe) that build and document aircraft pallets. In turn, commercial carriers pick up the pallets and deliver them to overseas customers. Provides unlimited service to Germany, Korea, Japan/Okinawa, Puerto Rico, Alaska, Hawaii, Guam, Panama, and Italy (USTRANSCOM, 1995: 2).

Consolidated Reparable Inventory (CRI)

Consolidated Reparable Inventory is inventory located in, or near, the repair shops, which contains enough reparable assets "on-the-shelf" to prevent the variability in the return pipeline from impacting the repair facility's ability to generate serviceable assets when required.

Consolidated Serviceable Inventory (CSI)

Consolidated Serviceable Inventory is centralized serviceable asset inventory, stored at the source of repair, which act as a serviceable buffer to provide responsive support to fill customer requirements. It is used to compensate for the uncertainty in customer demand, variability in transportation time, and the variability in the repair process (HQ USAF/LGM-2, 1995: 61).

Dedicated Service

Dedicated service is transportation (e.g. airlift, trucks) designated specifically for the movement of high priority sustainment assets (USTRANSCOM, 1995: 6).

Dedicated Surface

The origin depot provides tailored and scheduled service to a consignee.

Defense Transportation System (DTS)

The Defense Transportation System is an integrated system associated with the movement of Department of Defense owned or controlled materiel. It is comprised of DoD personnel, facilities, equipment, documents, systems, and those commercial applications and resources operating under the control or visibility of DoD (AFI 24-201, 1994: 16).

Demand

Identification of a customer requirement (SLMC).

Demand Driven Repair

Items are driven into repair based on actual customer consumption out of the CSI rather than quarterly negotiation. An automated tool will be used in the future to provide the source of repair with the daily induction requirements (SLMC).

Demand Driven Supply

Immediate shipment of assets from the CSI upon receipt of a requisition to fill customer requirements (SLMC).

Depot

The depot is a centralized repair facility for overhaul and high volume repairs.

Depot Level Reparable (DLR)

Depot Level Reparables are items requiring complete rebuild or major overhaul using more extensive facilities and equipment than are available at the base or intermediate levels (Pohlen, 1996).

Distribution and Repair In Variable Environments (DRIVE)

The Distribution and Repair In Variable Environments system is used to improve depot responsiveness to current and near-term operational requirements both in peace and war by providing information to manage the depot repair and distribution processes. DRIVE prioritizes repair and distribution actions to satisfy weapon system availability goals (HQ AFMC/SXMW, 1991: 6).

Door-to-Door Distribution (D^3)

Door-to-Door Distribution service involves commercial express carrier pick-up of cargo at designated points on base, and time-definite delivery of cargo to a designated receiving location (another base, depot; CONUS and OCONUS) while maintaining complete in-transit visibility (HQ USAF/LGM-2, 1995: 61).

Dynamic Multi-Echelon Technique for Recoverable Item Control (Dyna-METRIC)

Dynamic Multi-Echelon Technique for Recoverable Item Control is a series of capability assessment models developed by RAND to support analytic studying of the logistics system. Version 6.4, an advanced, hybrid analytic simulation model, the latest version of the Dyna-METRIC series, incorporates the indenture relationship among LRUs and SRUs (Cohen and others, 1991: xxi).

Dyna-METRIC Microcomputer Analysis System (DMAS)

Dyna-METRIC Microcomputer Analysis System allows unit-level logistics analysts to access and execute Dyna-METRIC capabilities to support unit- and base-level resource management decisions. DMAS provides the user with the capability of assessing unit-specific data (demand rates, repair times) and base-wide sources of on-hand stock quantities that have been extracted from the Standard Base Supply System (SBSS) (HQ AFMC/SXMW, 1991: 8).

Express Transportation

Express transportation leverages the relatively low cost and high reliability of fast transportation against the high cost of maintaining large inventories of spare parts. Express transportation is simply shipping assets by the fastest means possible and will be used to speed the shipment and return of Lean Logistics items (HQ USAF/LGM-2, 1995: 62).

Fully Mission Capable (FMC)

Fully Mission Capable is an aircraft status indicating that all of an aircraft's components are serviceable and the weapon system can accomplish any of its intended wartime missions (Isaacson and Boren, 1993: xv).

Get-Well Assessment Module (GWAM)

The Get-Well Assessment Module provides logistics managers with information and analysis tools to resolve logistics problems identified by the Readiness Assessment Module (RAM) and the Sustainability Assessment Module (SAM) (HQ AFMC/SXMW, 1991: 4).

High Priority Sustainment

High priority sustainment is defined as critical personnel and cargo that moves to/from the theater ahead of normal sustainment (non-unit) and deploying forces (unit) as determined by supported CINCs (USTRANSCOM MSG 271453Z Dec 95).

In-transit Visibility

In-transit Visibility is the capability provided to a theater combatant commander to have visibility of units, personnel, and cargo while in-transit through the Defense Transportation System

Lash-up

To meet up with. Example: Seamless Lash-up - to meet up with without delay.

Lean Levels

Lean Levels are Lean Logistics inventory authorizations that are designed to reduce traditional inventory levels approximately 30-40% by maintaining a system that is much more responsive and efficient (Ramey and Pyles, 1992: 7). These reduced levels of inventory are referred to as Lean Levels.

Lean Production

Lean production is a business practice that focuses on the reduction of inventory levels through the utilization of rapid transportation and continuous improvements in all processes (Pyles and Cohen, 1993: 3).

Line-Replaceable Units (LRUs)

Line-replaceable units are component parts or assemblies that are removed from the aircraft when a discrepancy is suspected (Abell and others, 1992: xx).

LOGAIR

LOGAIR was an AF contracted logistics cargo airlift system managed by the Air Force Logistics Command. The system consisted of a series of cargo hubs strategically located at each Air Logistic center within the CONUS. Each cargo hub was connected by a series of airlift routes that provided the movement of cargo to the hubs, enroute locations, and Military Airlift Command APOE's for delivery and pickup of additional cargo (Bruns, 1990: 3).

Logistics Pipeline

The logistics pipeline is a network of repair and transportation channels through which repairable and serviceable parts flow as they are removed from their higher assemblies, repaired, and requisitioned from other supply points (Isaacson and others, 1988: xv).

Maximum on Ground (MOG)

Maximum on Ground is the highest number of aircraft being used in an operation which will be allowed on the ground during a given span of time based on simultaneous support.

Mission Design Series (MDS)

A mission design series is an alphanumeric designation representing a single USAF aircraft type (e.g. F-16C). It is a specific aircraft design (including possible mission-dependent design extensions) that implies a specific configuration of components (Pyles, 1984: xv).

Mobility Footprint

A mobility footprint is the amount of personnel, materiel, and logistics support required for a deployment.

Mobility Readiness Spares Package (MRSP)

A mobility readiness spares package is an air transportable package of spares and repair parts required to sustain planned wartime or contingency operations of a weapon or support system for a specified period of time pending resupply (HQ USAF/LGM-2, 1995: 62).

Modifications Management System (MMS)

The Modifications Management System provides AFMC with information on weapon system modification requirements. The MMS portrays current weapon system/equipment readiness status by providing weapon system projections, logistics support levels, and funding programs necessary to achieve those requirements (HQ AFMC/SXMW, 1991: 9)

Monte Carlo Trial

A Monte Carlo trial is a replication of an experiment to estimate experimental error in which outcomes are determined purely by chance (Isaacson and Boren, 1993: 2-4).

Multi-Echelon Technique for Recoverable Item Control (METRIC)

Multi-Echelon Technique for Recoverable Item Control is a method for estimating requirements for aircraft recoverable spare parts developed by C. C. Sherbrooke of RAND (Adams and others, 1993: xxi).

National Stock Number (NSN)

The national stock number is a unique number assigned to identify a particular kind of item (Abell and others, 1993: xxx).

Not Repairable This Station (NRTS)

Not Repairable This Station is a decision or status given to reparable assets indicating that a component cannot be repaired by a specified facility (Pyles, 1984: xv).

Order and Ship Time (OST)

Order and ship time represents the average elapsed time between the initiation and receipt of stock replenishment requisitions from the depot (Christensen and Ewan, 1994: 5).

Organic

Assigned to and forming an essential part of a military organization. Example: organic cargo or organic airlift.

Pacific and Atlantic Express Channels

Pacific and Atlantic Express channels are AMC channel missions which provide reliable, daily CONUS to theater transportation of defense forces' high priority war-stopper cargo to the point of attack. The Pacific Express provides service from Travis AFB to Elmendorf, Yokota, Osan, Kadena, Fukuoka, Iwakuni, Misawa, Kimhae, and Kunsan. The Atlantic Express provides service from Dover AFB to Mildenhall, Ramstein, Aviano, and Incirlik. Average AMX possession time is 2 to 5 days on the Pacific Express and 2 to 4 days on the Atlantic Express (USTRANSCOM, 1995: 3).

Pallet, 463L

A 463L pallet is an aluminum air cargo pallet, 88 inches by 108 inches on which shipments are consolidated for movement by Air Mobility Command (AFI 24-201, 1994: 17).

Premium Service

Premium Service is a DLA service that uses a storage facility located near an overnight express carrier (Fed Ex in Memphis). Critical items are stored at the facility and when requisitioned, are picked up by the carrier and delivered to the customer within 48 hours (USTRANSCOM, 1995: 2).

Premium Transportation

Premium Transportation is express, time definite and guaranteed transportation.

Project Code

A project code is simply an identifier. Normally a project code is assigned to a piece of cargo to identify its final destination, association with a particular contingency operation or supporting mission.

Rapid Theater Distribution System (RTDS)

A theater-established rapid intra-theater distribution system to lash-up with AMX. Theater assets (C-12, Helicopter, COD, Panel Van) await the arrival of AMX at the theater distribution hub (similar to the CONUS hub) and after a fast sort cargo is delivered direct to forward units (HQ USAF/LGM-2, 1995: 62).

Readiness Assessment Module (RAM)

The Readiness Assessment Module assesses the overall readiness of weapon systems by comparing actual inventory, status, and utilization data with availability and mission capability requirements. Readiness is analyzed for each weapon system at the mission design series, command, and base and unit level. This allows the Weapons System Management Information System (WSMIS) user to maximize the number of fully mission ready aircraft by effective redistribution of resources (HQ AFMC/SXMW, 1991: 2).

Readiness Based Levels

Readiness based levels are pipeline allocation requirements to the depot and field based upon minimization of system expected backorders. The depot allocation is considered the depot working level (AFLMA, 1995: 6).

Requirements Execution Availability Logistics Module (REALM)

The Requirements Execution Availability Logistics Module is the software module of AFMC's Weapon System Management Information System (WSMIS) that computes requirements and identifies priorities for budget allocation and redistribution of available stock to meet wartime requirements, including strategic airlift requirements (Abell and others, 1993: xxx; HQ AFMC/SXMW, 1991: 5).

Repair on Demand

Repair of assets based on sale/distribution of a like asset from the CSI to a customer (SLMC).

Repair Pipeline

Portion of the repair pipeline (contractor or organic) that includes the time a reparable is driven into repair until the same asset becomes serviceable and available for shipment to a customer (SLMC).

Reparable Asset

Reparable assets are those items that can be repaired or reconditioned and returned to a serviceable condition for reuse (Christensen and Ewan, 1985: 1).

Retrograde

Retrograde cargo is materiel being transported from the retail level to the wholesale level (e.g., return of a reparable item from an operating base to a repair depot). For unit requirement, cargo evacuated from a theater of operations (AFI 24-201, 1994: 18).

Sustainability Assessment Module (SAM)

The Sustainability Assessment Module predicts the combat capability of tactical, strategic, and airlift weapon systems for a given set of operations plans, logistics assets, and logistics performance factors. SAM is used as the Air Force tool for the Major Commands to determine their SORTS C-level ratings (HQ AFMC/SXMW, 1991: 3).

Shop Repair Time

For depots, the time elapsed from receipt of a reparable at the depot repair shop until the item is turned in as a serviceable asset. For bases, the time elapsed from transfer to the back shop until made serviceable and returned to maintenance or supply (SLMC).

Shop Replaceable Unit (SRU)

A shop replaceable unit is a subcomponent of an LRU that is typically removed and replaced during repair of the LRU (Abell and others, 1993: xxxi).

Special Assignment Airlift Mission (SAAM)

A Special Assignment Airlift Mission is a mission operated by AMC (other than the 89th Airlift Wing) at the request of the Department of Army, Navy, or Air Force only (AFI 24-201, 1994: 18).

User-in-Control

Provides the user with the part where and when it is needed. This gives the MAJCOMs a larger role in deciding resource distribution and allocation of serviceable assets (SLMC).

Weapon System Management Information System (WSMIS)

The Weapon System Management Information System is the primary system used by AFMC which provides the capability to view the impacts of our logistics status on our potential wartime capabilities. WSMIS assesses each aircraft weapon system's readiness and sustainability, identifies those items and resources that limit the weapon system's achievement of specified readiness and/or sustainability objectives, and develops and monitors get-well plans to reduce the impact these items and resources have on the weapon system's combat capability. WSMIS consists of the Readiness Assessment Module (RAM), Sustainability Assessment Module (SAM), Get-Well Assessment Module (GWAM), Requirements Execution Availability Logistics Module (REALM), Distribution and Repair In Variable Environments (DRIVE) System, Automated Weapon System Master Plan (AWSMP) Module, and Modifications Management System (MMS) (HQ AFMC/SXMW, 1991: 1).

Abstract

Lean Logistics was developed in response to budget cuts, force reductions, and a new political world order. The primary objective of Lean Logistics is to minimize the total system wide costs of the Air Force organization. Currently, the Air Force is seeking to cut costs by reducing inventories, improving repair processes, and employing faster transportation where possible. The purpose of this thesis is to determine if the Air Mobility Express (AMX) current sizing plan is capable of supporting the retrograde assets generated during the sustainment portion of a war.

The Dyna-METRIC version 6.4 simulation program is employed to analyze the effect of varying such parameters as flying hours and retrograde shipment time on the weight and space required to move retrograde assets. Analysis of the results was accomplished using a Small Sample Test of Hypothesis. The results indicated that the current sizing plan is capable of handling the retrograde cargo generated by four F-16C squadrons for the six scenarios evaluated. This research also hints that while the current plan is capable of supporting four F-16C squadrons, it may not be sufficient to support the transportation of reparables for all weapon systems involved in the war effort. We recommend that the current AMX sizing plan be increased in order to accommodate the projected reparable asset cargo loads generated by two near-simultaneous major regional conflicts.

AN ANALYSIS OF AIR MOBILITY EXPRESS REQUIREMENTS OPERATING WITHIN A LEAN LOGISTICS WARTIME ENVIRONMENT

I. Introduction

Introduction

In response to budget cuts, force reductions, and a new political world order, the USAF developed Lean Logistics to support weapon system availability and readiness under new warfighting operational strategies. Lean Logistics is a series of interrelated initiatives designed to enhance combat capability while simultaneously reducing the operating costs of Air Force logistics systems. The primary focus of Lean Logistics is to reduce costs and investments in logistics infrastructure by streamlining the logistical policies, processes, and management structures that drive those costs (HQ USAF/LGM-2, 1995: 7).

In an effort to reduce costs, there are trade-offs associated with the logistics system that must be evaluated. In general, the objective is to minimize the total system wide costs of the Air Force organization. These costs include but are not limited to inventory carrying costs, requisition processing costs, and transportation costs (Glaskowsky and others, 1992: 20). Figure 1.1 depicts the logistics cost trade-offs of transportation and inventory in a simplified form. At one end of the spectrum (right), organizations maintain large stocks of expensive inventory to buffer inefficient and slow, inexpensive transportation services to preclude mission degradation. At the other end of

the spectrum (left), organizations maintain minimal inventory levels and rely on fast, efficient, more expensive transportation to move materiel to ensure mission readiness.

From this example, the trade-offs between transportation and inventory alternatives can readily be observed. As inventory levels and costs increase, transportation costs decrease. As inventory levels and costs decrease, transportation costs tend to increase. Furthermore, inventory costs typically decrease more than the transportation costs increase which results in an overall total cost savings. The point at which inventory and transportation costs intersect on the cost curve is the least total cost logistics alternative. It is this point; the total cost savings which results with minimum inventory and express transportation services that Lean Logistics emphasizes.

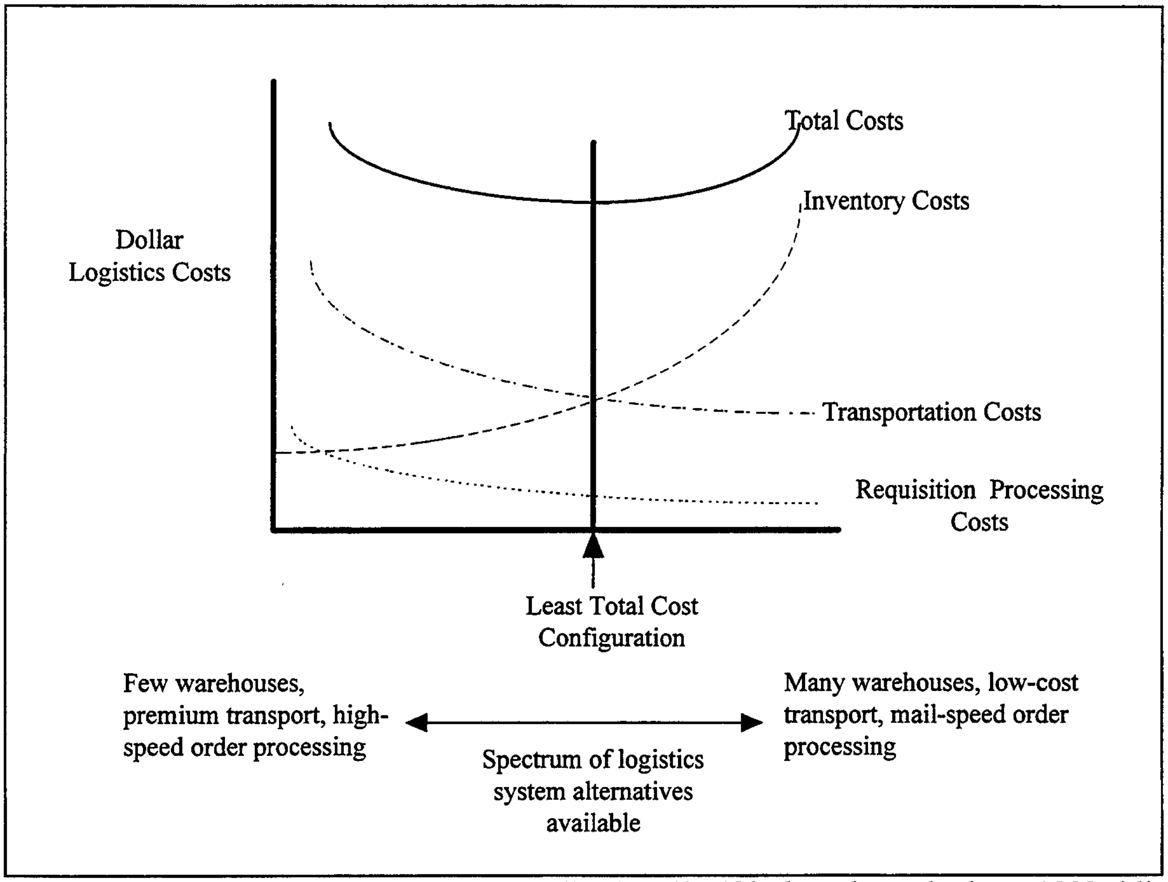

Figure 1.1 Transportation - Inventory Trade-offs (Glaskowsky and others, 1992: 20)

As a result of the new world environment, the U.S. military had to adjust its forces to accommodate changing threats, with the Air Force playing an ever increasing role through its goal of Global Reach - Global Power (GR-GP) (HQ USAF/LGM-2, 1995: 10). GR-GP implies a flexible and responsive support system capable of supporting forces facing a wider array of missions, roles, and scenarios. Lean Logistics provides this flexibility through reduced reparable inventories, priority depot repair processes, and express transportation services to support these forces during peacetime and wartime. With reduced inventories at the bases and the depot, the logistics

infrastructure relies on fast transportation to move reparable assets to where they are needed, when they are needed, to support mission readiness and aircraft availability goals.

During military contingency operations, there is an increased need to ensure some type of "express" airlift is in-place to move high priority reparables to the theater of operations. To support this need, the Air Staff Transportation Reinvention Laboratory developed Air Mobility Express (AMX) to transport large shipments of Depot Level Reparables (DLR's) and other critical items on a daily basis to and from the theater. AMX is the military adaptation of commercial overnight delivery. It consists of the express carrier's CONUS infrastructure, Air Mobility Command (AMC) aircraft [Civil Reserve Air Fleet (CRAF) carrier or organic] and a Rapid Theater Distribution System (RDS) for express two-way movement within the theater (Joint Pub 4-01, 1995: III-3).

This thesis examines the requirements generated by Lean Logistics on Air Mobility Express (AMX) under various operating conditions during the sustainment portion of a wartime scenario. This chapter provides a brief overview of the Lean Logistics concept followed by an introduction to AMX. In addition, this chapter will discuss the overall research objectives, scope, limitations, and the research methodology to be used. This chapter concludes with an overview of the thesis.

Lean Logistics

According to the 1995 DoD Logistics Strategic Plan, "the mission of DoD logistics is to provide reliable, flexible, cost-effective and prompt logistics support by

making select investments in technology, training, process re-engineering, and continually pursuing better business practices" (DoD, 1995: 4). Traditionally, logistics philosophy emphasized a "mass-logistics" paradigm which placed heavy emphasis on three mechanisms for providing logistical support (Girardini and others, 1996: 19):

1. Functional bureaucracies utilizing numerous lateral hand-offs of supplies across organizational boundaries to execute processes.
2. Large inventories to cover for logistical inefficiencies and inaccurate demand forecasting.
3. Special management actions such as expediting high-priority requisitions and intensively managing resources.

These management techniques tend to lead to inflexibility, unresponsiveness, increased manpower needs, and poor process performance. If the logistics process is not responsive, then large investments in pipeline inventory (material "in process" rather than "in use") is required. Material "in process" does not contribute to weapon system availability. As a result these management techniques prove to be inefficient especially in today's climate of reduced budgets and demand uncertainties (Girardini and others, 1996: 19).

This climate of reduced budgets and demand uncertainties centers around the collapse of the Soviet Union. With the collapse of the Soviet Union, the location of the next conflict can no longer be accurately predicted. As such, the military must be capable of responding quickly to a variety of locations and intensities - flexibility is the key. Additionally, budget reductions have encouraged the extension of current weapon

systems service lives along with the incorporation of some new weapon systems. With many of the weapon systems remaining in the DoD inventory well into the next century, logistics must support a broader range of old and new technologies (DoD, 1995: 7). This broad range of technologies in conjunction with the shift from global to highly diverse regional conflicts demands flexible logistics support in order to maintain weapon system readiness.

The pressures of the new world order demanding an inexpensive, flexible logistics system prompted the need for a new "lean" philosophy to management. Lean Logistics evolved as a result of the 1989 Defense Management Review (DMR) and RAND Project Air Force research. This research was conducted to benchmark new business practices and innovative organizational or process changes that might transform the USAF logistics system to meet future challenges (GAO, 1994: 5; HQ USAF/LGM-2, 1995: 17). The goal of Lean Logistics is to "maximize operational capability by using high velocity, just-in-time processes to manage mission and logistics uncertainty in-lieu of large inventory levels" (HQ USAF/LGM-2, 1996: 2). This Lean Logistics goal relies heavily on an agile logistics support network.

Agile Air Force logistics systems require a more lean way of thinking--shorter repair cycles; greater reliance on transportation, not storage, to deliver material; and swifter mobility with better knowledge of where all assets are located (HQ USAF Slide Package, 1995). Shorter repair cycles lead to the movement of reparables quickly through the repair process by eliminating non-value-adding activities and simplifying the

process overall (priority repair versus traditional batch repair). In addition, fast transportation replaces large stocks of inventory by keeping reparable parts "flowing" through the pipeline. This minimizes the number of assets required to support weapon system readiness and aircraft availability, while reducing system-wide costs.

Finally, total asset visibility (TAV) of reparables provides commanders with the knowledge of where their spare parts are located at all times, whether they are at the depot in repair or in transit on their way back to the theater. In addition, TAV allows commanders and decision makers to evaluate asset status (levels, condition and flow times of reparables) in near real time and redirect assets as required to support operational units (HQ USAF/LGM-2, 1996: 9). When combined, shorter repair cycles, faster transportation, and asset visibility provide an atmosphere more suited to quick response to whatever situation arises. In other words, the logistics system (inventories, maintenance equipment, transportation, etc...) will have the flexibility to be redirected in response to conflict locations and intensities.

Tenets of Lean Logistics. The objective of Lean Logistics is to provide responsive support to achieve mission effectiveness and aircraft availability goals while minimizing total costs to ensure readiness and sustainability in both peace and war (HQ USAF, 1995: 11). Lean Logistics employs the basic concepts of lean production management practices that were adopted in the commercial industry as an alternative to mass production. Some of these practices specifically apply to USAF logistics and include designing for a smaller footprint, fast transportation, repair-on-demand, and an

overall tighter integration of processes (HQ USAF/LGM-2, 1995: 18). Lean Logistics can be described as an application of best business practices with the following tenets:

1. Empower the operational commands so that they have more control over the logistics resources that directly affect the weapon system readiness and sustainability.

2. Develop "just-in-time" logistics so that materiel management and distribution processes are much more responsive while buffer stock and real-time management decision-making are greatly reduced.

3. Tighten repair and manufacturing so that management is simplified, non-value added actions and indirect labor are reduced, and "repair-on-demand" can be implemented with small amounts of system-wide stocks.

4. Use managed competition to improve organic and contractor performance, not just on cost, but on a wide range of measures pertinent to Lean Logistics.

5. Expand Integrated Weapon System Management (IWSM) to ensure that weapon system designs are well suited to lean production and lean support systems.

6. Embed continuous improvement so that the logistics leadership expects and seeks to improve system performance constantly rather than simply meet standards. (Cohen and others, 1994: 3-4)

Empowering Commands. Empowering the commands means extending the commands' responsibility and authority over day-to-day management of reparable stock and repair priority and destination decisions. This would allow direct control over processes that directly affect weapon systems availability and sustainability and the delivery of ready forces (Cohen and others, 1994: 7). Through this empowerment

MAJCOMs would be allowed to allocate available asset levels within their own commands to assure depot repairs and requisition fills support the most important missions even when they cannot be formally declared (HQ USAF/LGM-2, 1995:19). The rationale for this concept is that since users are closer to their units' needs for various components, they are in the best position to determine relative priorities (Cohen and Pyles, 1992: 3). This in turn allows command input into purchases which provide the most benefit in terms of aircraft availability within their budget.

Just-in-Time Logistics. Just-in-time logistics means responding to changing needs, and reducing inventories, indirect activities, and costs. Key features of this type of logistics system include reducing worldwide stock at the bases and depots through central stock leveling, rapid daily transportation with fixed schedules, and streamlined repair processes. As the current world environment requires the military to be capable of responding to a multitude of conflicts, maintaining inventories near each potential region of conflict would generate large costs. By incorporating a just-in-time philosophy, the Air Force can respond to potential conflicts through faster transportation and lower inventories without incurring large costs.

Tightened Repair and Manufacturing. Tightening repair and manufacturing results in improving depot and base repair flow times, quality, and surge capability (Cohen and others, 1994: 11-13). This is accomplished by adopting priority repair procedures (customer driven supply) and reducing throughput times; a direct result of streamlining processes for repair and manufacturing. By tightening the repair and

manufacturing process, repairs are made as needed and not held for batch processing, inefficiencies are removed from the process, and the quality of the products is improved (shortening the repair pipeline). This reduces the need for costly inventories to buffer lengthy pipelines.

Managed Competition. Managed competition is essential to improving lean production capabilities at the depots. According to Cohen and others, "it is seen as a critical means for incentivizing the organic and contractor production systems so that Lean Logistics can be successfully implemented and used" (1994: 19). The primary goal is to be able to compete particular workloads among organic and contractor organizations to improve lean production capabilities, flexibility, and responsiveness. Managed competition seeks to reduce costs through the incorporation of the most efficient source of production - be that organic or contract.

Integrated Weapon System Management. From a Lean Logistics perspective, Integrated Weapon System Management focuses on the development of products and product repair/manufacturing support. Emphasis is placed on developing products with end-user inputs reflected throughout the entire development cycle, from concept, to design formulation, implementation, and development outputs, including formal evaluation (Cohen and others, 1994: 20). This emphasizes the incorporation of methods to reduce costly inventories, increase transportation speed, and increase aircraft availability at the earliest possible stages of the development process.

Continuous Improvement. Embedding continuous improvement ensures that logistics processes are always being assessed and evaluated for further improvements to reduce costs and improve aircraft availability. This contrasts with traditional logistics, where support systems were managed to goals or standards and then typically forgotten.

Transportation

A key premise in Lean Logistics philosophy is the availability and responsiveness of the transportation system. The tenets of Lean Logistics institute a logistics system which streamlines processes by centralizing inventory responsibility, inducting priority repair procedures, and moving reparable components via express transportation to the bases and the depot. The cost of a transportation system failure to deliver a critical item when and where required may be significant in terms of carcass backlogs generated, weapon system down time, and overall mission readiness. Therefore, we need to ensure adequate, reliable transportation is available to transport reparable spare parts during peace and war to ensure weapon system readiness and sustainablility.

During peacetime, several transportation services exist to ensure the responsiveness of high priority materiel movement. These are Air Mobility Command (AMC) channel support, AMC Pacific and Atlantic Express missions, Commercial Air Lines of Communication (COMALOC), Air Lines of Communication (ALOC), commercial overnight carriers, premium service, dedicated surface, commercial charters, and Special Assignment Airlift Missions (SAAM) (USTRANSCOM MSG 271453 December 1995). During a contingency, lack of suitable airlift and hostile conditions in

the Area of Responsibility (AOR) may diminish or eliminate these peacetime options. As a result, the United States Transportation Command's High Priority Sustainment Delivery Study Group agreed that a single, pre-planned, reliable system be selected for wartime use only; that system is Air Mobility Express (USTRANSCOM MSG 271453 December 1995).

Air Mobility Express

"Air Mobility Express was developed to provide rapid, time-definite delivery and retrograde movement of joint sustainment assets identified by the theater commander as having an immediate impact on combat capability" (Joint Pub 4-01, 1995: III-10). The current sizing plan calls for using one AMC aircraft (CRAF carrier or organic) to deliver reparable assets to and from the AOR on a daily basis (HQ AMC/DOJ, 1996: 3). Movement on AMX is based on a pre-determined priority system and aircraft are shared by all military services. Delivery from the Continental United States (CONUS) to the AOR is set at 1-3 days from point of origin to end-user. AMX must be integrated with a theater distribution system to provide a seamless lash up for onward movement to the end-user.

With such an emphasis on transportation to move fewer reparable assets between the bases and the depot, AMX appears to be a key component to the success of Lean Logistics operations during contingencies. AMX ensures time-definite delivery of parts which reduces the requirement for large stocks of reparables at the bases, and reduces reparable pipeline times with express transportation service. Time-definite delivery of

spares and lower reparable pipeline times translates into reduced expected backorders across the fleet and reduced reparable backlogs at the aerial port of embarkation (APOE).

Problem Statement

Lean Logistics is a philosophy that seeks to improve the responsiveness of the Air Force Logistics pipeline by consolidating the reparable asset pipeline and streamlining the flow of assets through the repair process. This research examines the level of support that Lean Logistics would provide to wartime deployed forces after the first 30 days in combat utilizing one AMX aircraft on a daily basis as its primary mode of parts transportation. In the context of this research, level of support refers to the amount of strategic airlift space available to transport reparables and carcasses under the constraint of wartime sustainment.

The problem faced by the USAF is two-fold:

1. Determining if the current AMX sizing plan is sufficient to handle the space and weight requirements for retrograde reparables generated by Lean Logistics under various operating conditions.
2. Determining the length of time required to eliminate the cargo backlog (build-up of reparables) under current AMX sizing plans.

Research Objectives:

This research will determine how a Lean Logistics transportation system will react during the sustainment portion of a wartime scenario. Converting to a compressed supply pipeline generates a corresponding increase in the required reliable, fast

transportation necessary to move spares between the bases and the depot. This is a direct result of leaned inventories and fewer spare parts available at the bases. In the past, traditional logistics systems maintained large stocks of expensive inventory to act as a buffer for slow transportation and slow repair processes. Now, with fewer parts in the system, faster, more reliable transportation is required to keep the flow of spare parts moving.

Two constraints (increased threat and maximum on ground) will be placed on the logistics pipeline to ascertain the resultant transportation backlogs at the port, the time it will take for those backlogs to be eliminated, and the number of AMX aircraft required to avoid a backlog. The effects of these constraints will be analyzed together with two separate combat aircraft flying hour profiles - high and low.

There are three primary objectives to this research:

1. Of particular interest is the capability of AMX to support the tactical portion of a contingency operation. This research will determine the impact of using only one AMX aircraft per day to transport reparable assets in a wartime sustainment scenario. By analyzing the space required for retrograde parts and the amount of time required to eliminate any backlogs, conclusions may be drawn on the capability of the current AMX plans to accomplish its wartime tasking under Lean Logistics.

2. The second objective of this research is to determine the impact of variations in the retrograde shipment time (RST) on expected cargo backlogs at the outbound port, using AMX to transport reparables back to the depot. RST represents the transportation

time lag in the pipeline for transporting reparable carcasses from the base to the depot. This is not to be confused with Order and Ship Time (OST) which is the average time it takes to transmit a stock replenishment requisition between a given base and the depot, plus the depot response time for packing and crating the serviceable asset, plus the shipment transit time from the depot to the base. Many factors can effect the time it takes to ship a reparable carcass back to the depot after placing a demand on supply. Factors such as exceeding Maximum on Ground (MOG), increased threat, inclement weather, and in-flight mechanical problems can delay delivery of mission critical parts (thereby lengthening the pipeline) back to the depot for repair. Evaluation of this aspect of Lean Logistics is essential to determining the overall impact of Lean Logistics in conjunction with AMX plans on mission accomplishment.

3. The third objective of this research is to determine the effect that variations in flying hours has on expected backlogs at the port. Assuming failure rates are directly proportional to total flying hours, increasing the flying hour program would generate a corresponding increase in demands for reparable spare parts, thus an increase in retrograde carcasses. By analyzing variable flying hours, conclusions can be drawn on the capability of one AMX aircraft to handle the retrograde carcasses from the base to the depot.

Scope of the Research

This research analyzes the effect of cargo aircraft space limitations and the resultant backlogs generated for in-theater combat aircraft reparables. The variable flying

hour program used is hypothetical and is not drawn from any specific warplan. This program is representative of a notional tasking which would typically be used by fighter aircraft. The primary focus will be on the reparable parts backlog generated by four squadron-sized units in an air-to-ground role.

Cargo backlog was chosen as the variable of interest as it directly shows the current AMX sizing plan's capability to provide transportation support for reparables. An excess backlog of reparables results in congested port operations, increased expected backorders across the fleet, and degraded asset visibility outside the theater for each weapon system involved in the conflict.

The type of weapon system studied in this research will be limited to one type of mission design series (MDS). The MDS used in this research was scoped to include only close air support aircraft. Close air support aircraft were chosen because of their high potential for damage sustainment in a war. This type of weapon system is representative of both heavy flying and high numbers of battle damaged reparable part failures. As such, this MDS represents a worst case scenario for reparable failure.

The number of reparables studied in this research will be further limited to include only the top 25 critical items assigned to the weapons system's Mobility Readiness Spares Package (MRSP). Studies conducted by HQ AFMC/XPS verify similar results between the top 25 LRU and all MRSP LRU's when analyzed (Niklas, 1996). Using the top 25 critical assets is a valid depiction of AMX transportation objectives as AMX was intended to transport only high priority sustainment items.

Additionally, this study will be limited to the first thirty days of the sustainment portion of the wartime scenario. This time period is of primary interest due to the expected impact by Lean Logistics on the transportation requirements during this phase. The transportation required during the deployment phase should decrease as the inventory contained within the initial MRSPs will decrease (i.e., more space is available on strategic airlift initially). Because of the decreased level of supply in the MRSPs, it is suspected that the transportation during the sustainment phase will increase. The deployment and reconstitution phases will be left to further research.

The transportation scenarios will be limited to the following:

1. Maximum on Ground (MOG) will be exceeded, lengthening the RST to determine the impact on backlogs generated

2. Threat in the Area of Responsibility (AOR) will be increased, preventing the cargo aircraft from landing. This will also lengthen the RST and the resultant backlogs generated will be determined.

Limitations of the Research

Although this study will attempt to be comprehensive, there are limitations to the applicability and generalization of the results of this research. The research is limited by the following factors:

1. The results of this research should be applied only to fighter aircraft and not generalized to other aircraft types such as cargo, tanker, and bomber aircraft with

deployment missions and spares support that are different from a deployed fighter unit. The study is designed to look at a deployed fighter operations environment.

2. The results of this research should be generalized only within the timeframe of this wartime simulation. This study is limited to the combat scenario and logistics support which occurs after the first 30 days of war - the sustainment portion of the wartime scenario.

3. The results of this research apply only to situations where the experimental conditions are the same as those modeled in this research. For example, the Dynamic Multi-Echelon Technique for Recoverable Item Control (Dyna-METRIC) Model generates item failure rates based on total flying hours or number of sorties. The results should not be generalized to situations where failure rates are not strictly correlated with flying hours or number of sorties. For the purposes of this research, failure rates are assumed to be based on total flying hours.

Assumptions

1. The assumptions made in this research effort are those assumptions which limit the Dyna-METRIC versions 4.6 and 6.4 and the Aircraft Sustainability Models described in Chapter 2 of this thesis.

2. The variable factors which are considered include the variability of flying hours and RST resulting from the wartime deployment scenarios: MOG exceeded and increased threat. All other input factors will be held constant throughout the study.

3. Initial spares availability and their location within the modeled pipeline will be determined by the application of the Aircraft Sustainability Model (ASM) version 3.0. This is necessary to ensure that appropriate initial conditions are set for a Lean Logistics environment for use by the computer simulation model.

4. AMX was developed to transport only high priority sustainment cargo to and from the theater of operations. High priority sustainment cargo is equivalent to the top 25 critical items for each MRSP. All remaining MRSP items and other reparables are transported to and from the AOR via opportune airlift or other methods.

5. Reparable failure rates are based on flying hours and are strictly correlated with flying hours.

Investigative Questions

The following investigative questions will be answered to evaluate the transportation portion of the Lean Logistics philosophy:

1. What is the current AMX sizing plan cargo capacity for Air Force reparable assets?
2. What are the transportation delay times associated with different environmental situations associated with conflicts?

By determining the space available for Air Force assets on AMX, resultant backlogs can be generated. This will indicate whether current AMX sizing plans are sufficient to transport critical assets for air-to-ground weapons systems under ideal port

conditions. The transportation delay times associated with the two scenarios are necessary to determine additional backlogs generated by non-ideal situations (exceeded MOG, increased threat, etc...). This will give further insight into the level of support offered by the current AMX sizing plan.

Measurement Questions

The following measurement questions will be answered to provide necessary information to this research:

1. What are the percent base repair (PBR), repair cycle time (RCT), and demand rate per flying hour for an air-to-ground weapon system National Stock Number's (NSN)?
2. What are the air-to-ground weapon system's average number of sorties per aircraft per day, the expected flight duration, turn rates, and attrition rates?
3. What are the top 25 NSN's critical to mission capability?
4. What are the air-to-ground weapon system's lean inventory levels?

Research Methodology

Various tools will be used to accomplish this research. Transportation delay times for the above mentioned operational scenarios will be determined by experts in the field. Dyna-METRIC version 4.6 will be used to generate a problem parts list of the top 25 critical items for air-to-ground aircraft. The Aircraft Sustainability Model version 3.0 will be employed to determine leaned levels for the top 25 critical assets as determined by Dyna-METRIC version 4.6. The resulting leaned levels for the top 25 critical assets will then be integrated into Dyna-METRIC version 6.4 to simulate logistical support for four

air-to-ground aircraft squadrons operating in a wartime scenario. Dyna-METRIC version 6.4 will then generate the retrograde list from the pipeline quantity report based on the leaned levels and appropriate scenario data. A Microsoft Excel version 5.0 spreadsheet will be developed to calculate the backlogs generated by AMX capacity limitations (if any). In addition, any backlogs generated by the non-ideal scenarios (exceeded MOG and increased threat) will be calculated. This data will be analyzed using a small sample T-test to determine the statistical relevance of the results.

Management Implications

This study is relevant for the following reasons:

1. This study will show the impact of the AMX sizing plan on cargo backlogs to determine if current plans are sufficient to keep reparables flowing through the pipeline.
2. This study will indicate how long it takes to eliminate any cargo backlogs generated.

A positive indication on the success of AMX within the Lean Logistics environment will give decision makers more information to justify the current AMX sizing plan. A negative indication of the success will provide decision makers an opportunity to re-evaluate current plans and make changes if necessary prior to a conflict.

Chapter Summary

This chapter provided a review of the Lean Logistics concept and the six basic tenets of Lean Logistics. A discussion of the importance of a responsive transportation

system was introduced with an emphasis on Air Mobility Express operations. In addition, the overall research objectives, scope, limitations, and the research methodology to be used were discussed.

Thesis Overview

Chapter II will provide an in-depth review of the literature on the numerous subjects required to perform this study. Subjects presented will include Lean Logistics, its evolution and underlying theories; transportation, its role under Lean Logistics, and the Air Mobility Express concept of operations. In addition, Chapter II will review reparables and the reparable pipeline to include base stockage policy , and base and depot repair procedures. Finally, the chapter will conclude with a review of the models to be used to conduct the Lean Logistics performance analysis, Dyna-METRIC Model versions 4.6 and 6.4 and the Aircraft Sustainability Model version 3.0.

Chapter III will describe why each type of model was chosen to perform the analysis, delineate the specific hypotheses used to evaluate the ability of Air Mobility Express to support the sustainment portion of a wartime operations tempo under Lean Logistics, describe how the Aircraft Sustainability Model version 3.0 and Dyna-METRIC (versions 4.6 and 6.4) are used to generate the necessary data, and describe the statistical analysis used to verify the relevance of this study.

Chapter IV will present results and analysis of the data generated. First, it will discuss the Dyna-METRIC 4.6 output of the top 25 critical items. Next, the ASM output for the leaned MRSP stock levels will be explained. The Dyna-METRIC 6.4 retrograde

pipeline report will then be analyzed for each scenario and inventory level. Finally, the Microsoft Excel spreadsheet used to calculate the backlogs generated by AMX capacity limitations (if any). In addition, any backlogs generated by the non-ideal scenarios (exceeded MOG and increased threat) will be calculated. Chapter V will provide conclusions, recommendations and suggestions for additional research.

II. Literature Review

Introduction

The purpose of this chapter is to provide a review of the literature pertaining to Lean Logistics and subjects needed to perform this study. This chapter begins with a brief background of the events which led to the development of the Lean Logistics concept. It then proceeds with an introduction to Lean Logistics and its evolution, followed by a discussion of its underlying theories. Next, this chapter addresses the evolution and role of transportation under Lean Logistics with an emphasis on Air Mobility Express (AMX), followed by a review of reparables and the reparable pipeline to include base stockage policy, and base and depot repair procedures. The chapter concludes with a review of the Multi-Echelon Technique for Recoverable Item Control (METRIC) based models used to perform this study: the Dynamic Multi-Echelon Technique for Recoverable Item Control (Dyna-METRIC) Model, and the Aircraft Sustainability Model (ASM).

Background

Prior to 1990, the Cold War defense policy required the US military to simultaneously support a global war and at least one major regional conflict. With the collapse of the Soviet Union, DoD began downsizing its forces and changed the defense strategy to support two near-simultaneous major regional conflicts (MRC). This new strategy requires DoD to be able to react to an unpredictable operations tempo, placing an increased premium on transportation to project and sustain forces (DoD, 1996: 6; Rutherford, 1995: 1). It requires an increased responsiveness, robustness, and

nimbleness. As a result, DoD must adopt new management and business practices that will allow for high levels of readiness and sustainment with limited resources. These practices refer to the "processes, practices, and systems identified in public and private organizations that perform exceptionally well and are widely recognized as improving an organization's performance and efficiency in specific areas" (GAO, 1995: 2).

In July 1989, the Secretary of Defense issued the Defense Management Report (DMR) to implement the Packard Commission's recommendations on streamlining and restructuring DoD business operations (GAO, 1994: 5). As a result of the DMR, the "Lean Logistics" concept was developed at the request of the Air Force Deputy Chief of Staff for Logistics by RAND's Project AIR FORCE (PAF), through its Business Practices Study (Cohen and others, 1994: 1). To understand the term "Lean Logistics," it is first necessary to understand what is meant by logistics.

Logistics

The importance of a robust, responsive logistics network in the military cannot be overemphasized. The following definitions provide various interpretations of what logistics means and how it can be applied in the field. For example, the military's definition of logistics is often cited as:

> ... the bridge connecting a nation's economy to a nation's warfighting forces. Logistics is the process of planning and executing the movement and sustainment of operating forces in the execution of a military strategy and operations. (Joint Pub 4.0, 1995: I-1)

However, the Council of Logistics Management's definition of business logistics, cited by Blanchard in Logistics Engineering and Management, is as follows:

> Logistics is the process of planning, implementing and controlling the efficient, cost-effective flow and storage of raw materials, in-process inventory, finished goods, and related information from point-of-origin to point-of-consumption for the purpose of conforming to customer requirements. (1992: 3)

In effect, the essential difference between these two general definitions is that military logistics emphasizes the movement of personnel and materiel in support of the war effort, whereas commercial logistics devotes primary attention to the movement and storage of products and supplies. Moreover, the Society of Logistics Engineers defines logistics as:

> The area of support management used throughout the life of the product or system to efficiently utilize resources assuring the adequate consideration of logistics elements during all phases of the life cycle so that timely influence on the system assures an effective approach to resource expenditures. (Coyle and others, 1992: 8)

This definition of logistics emphasizes the life cycle of a product--its reliability, availability, maintainability, and costs associated with supporting the product over its lifetime. This life-cycle costing is used as a basis of comparison for alternative products in the procurement process.

An effective logistics network is crucial to winning any conflict. Sustaining forces in wartime has become an ever-greater challenge as logistics managers are forced to respond to a wider range of scenarios with reduced resources. Unprojected spikes in operations tempo and the need to swing forces between theaters contribute to a greater need for assured continuing logistics support (DoD, 1996: 6-7). Unfortunately, maintenance of large stockpiles of spare parts and full deployment of traditional backshop repair capability is no longer practical and is inconsistent with the need to decrease the

mobility footprint. Spares are increasingly high tech and costly to support. This has led to the maintenance of essential components being performed in CONUS and other rear areas rather than in theater.

It is therefore important that joint warfighting capabilities coincide with changing DoD logistics concepts. In a memo regarding the 1996 USAF CINC's Conference, HQ USAF/LGXX cites the following changing logistics concepts:

> An increased emphasis on faster order and ship times, a shift from storage to time definite transportation as the primary contributor to that ship time, and of greatest concern, the need for an agile logistics system, supported by assured retrograde and resupply of reparable spares, that is robust enough to respond over a wide range of operational demands. (Navarra, 1996: 2)

These principles are reflected in the emergence of the USAF's Lean Logistics initiatives and drive a need for a rapid, time-definite delivery and retrograde movement of critical combat assets.

Evolution of Lean Logistics

Five external factors have driven the USAF to adopt a Lean Logistics philosophy: the changing threat, demand uncertainty, increasing costs, increasing reliance on aircraft availability, and the complexity of the current system.

Changing Threat. The end of the cold war and the beginning of a new world order created a new fiscal environment with a reduced budget available for defense needs and a significant reduction in end-strength (HQ USAF/LGM-2, 1995: 10; Cohen and others, 1991: 2). As a result, USAF logistics organizations face major challenges in being able to maintain a high degree of readiness and sustainablility. With a clear shift

away from global conflict, the Air Force faces a wider array of missions, roles, and scenarios that must be supported. This changing threat places less emphasis on force structure and new weapon systems and more reliance on a robust, flexible logistics support system.

A robust, flexible logistics support system must be capable of moving spare parts faster through the pipeline. Put simply, the faster spare parts move through the pipeline, the fewer parts are required. Fewer parts are required to buffer the inefficiencies which result from slow, unreliable transportation and batch repair processes. This, in turn, results in cost savings in inventory and improved customer support. In the past, DoD maintained large investments in inventories to preclude parts shortages in response to slow, uncertain transportation, cumbersome batch repair, and static processes. However, with a declining budget, DoD had to replace inventory size with inventory speed to preclude negatively impacting force readiness and sustainability.

Demand Uncertainty. The Air Force has faced long-standing difficulties in forecasting demands and subsequent repair requirements (HQ USAF/LGM-2, 1995: 11). As a result, inventories contain large buffer stocks to account for uncertain demand in military operations. These buffer inventories are expensive and difficult to manage. The answer is a logistics system that can rapidly readjust its operations to respond to the needs of military forces in increasingly unpredictable situations. Again, the ability to trade reliable, express transportation for inventory is a must to maintain force readiness in unpredictable situations. When reliable, express transportation services are available, less inventory is required to buffer demand and supply uncertainties.

Increasing Costs. The third factor is the increasing costs of spares, manpower and equipment, transportation, information, and repair. The mass production business practices of the past were predicated on the availability of rich logistics resources--personnel, stocks, facilities, equipment on a large scale--that the Air Force can no longer afford (Cohen and others, 1994: 2). With on-going budget reductions, it is necessary to reduce the logistics system costs on a system-wide, life-cycle cost basis. While overall costs would be less, some individual cost components might increase. The USAF Baseline Lean Logistics Master Plan and Road Map defines the Lean Logistics objective of decreased total costs as "eliminating non-value-added activities and resources (reduced labor and work-in-process), seeking more efficient sources for some services, and rebalancing resource allocation across functional areas (spares vs. transportation)" (HQ USAF/LGM-2, 1995: 14).

Increasing Reliance on Aircraft Availability. The USAF will require Lean Logistics and AMX to support a two MRC scenario in an environment requiring decreasing defense budgets. A two MRC scenario relies on sustained operations of combat aircraft to conduct war and strategic airlift to support forces. Sustained flying operations are reliant on logistics organizations getting the right spares and materiel, to the right place, at the right time, in the right condition. This responsive logistics support required in the new environment can best be accomplished with AMX and Lean Logistics initiatives such as shorter cycle times, shorter repair times, and time definite delivery (Pohlen, 1995).

Complexity of the Current System. Finally, the complexity of the current system encourages excess inventories, batch repairs, and slow, cumbersome transportation. The effects of these external factors result in an expensive, unresponsive logistics system with malpositioned inventories, and unmet customer expectations (HQ USAF Slide Package, 1996). As a result of these factors and their threat to maintaining aircraft availability, the pressures of new world demands led to the evolution of the Lean Logistics concept. Information in Table 2.1 was taken from a 1994 HQ USAF Lean Logistics briefing and compares key characteristics and processes changing today's traditional mass logistics to the proposed Lean Logistics of the future (HQ USAF Slide Package, 1994).

TABLE 2.1

CHANGING THE LOGISTICS BUSINESS

TODAY'S LOGISTICS	LEAN LOGISTICS
CHARACTERISTICS: - Big Inventory - Slow Uncertain Transportation - Cumbersome Batch Repair - Static Processes - High Cost	**CHARACTERISTICS:** - Smaller Inventory - High Velocity/Reliable Delivery - Optimum Repair Flow/ Repair on Demand - Continuous Improvement - Reduced Investment
BASE PROCESSES: - Large Capital Investment -- Big Peacetime Operating Stock (POS) -- Big Readiness Spares Packages (RSP) -- Big Footprint	**BASE PROCESSES:** - Lean Two-level Maintenance -- Smaller Tailored Stocks -- Streamlined Support Packages -- Light Footprint
BOTTOM LINE - Big Inventory Drives Infrastructure	**BOTTOM LINE** -Innovations Streamline Infrastructure

Lean Logistics Philosophy

Lean Logistics, as defined by Cohen and others, "is the application to the Air Force logistics system of technological and management innovations that have been proven in the commercial world, are relevant to the central support problems of the Air Force and are achievable at very affordable costs" (1994: 1). It is an interrelated series of logistics initiatives that promote combat capability, enhance war fighting sustainability, shrink the logistics footprint, and reduce infrastructure (Morrill, 1994: 8). Lean Logistics seeks to maximize operational capability by using high velocity, just-in-time processes to manage mission and logistics uncertainty in-lieu of large inventory levels (HQ USAF Slide Package, 1995). The resulting logistics system will be more effective, more

efficient, and more affordable. Lean Logistics will achieve cost reductions through simplified processes, improved management, increased flexibility, lower overhead, and reduced infrastructure (Cohen and others, 1994: 2). The information in Table 2.2 is drawn from a briefing package prepared for General Viccellio in June of 1995 (HQ AFMC Slide Package, 1995). It compares some elements of the traditional logistics management concepts to those proposed under a Lean Logistics philosophy.

TABLE 2.2

COMPARISON BETWEEN TRADITIONAL AND LEAN LOGISTICS CONCEPTS

Process	Today	Tomorrow
Requirements Determination	Buy and repair based on forecast of uncertain future	Buy and repair in response to actual operations tempo
Stock Control and Distribution	Store and ship just-in-case	Store and ship just-in-time
Workload Management	Man to negotiated workload	Man to throughput
Production	Accept variable, long cycle times	Require consistent and reduced cycle times
Depot Maintenance Financial Processes	Focus management information and metrics on output efficiency	Focus management information and metrics on throughput and cost

The Air Force can capitalize on existing capabilities and make the transition to Lean Logistics easier by using proven commercial technologies already in place. For example, changing technology has provided an information revolution, sophisticated communications, and a world-wide civilian logistics infrastructure. With respect to transportation practices, Lean Logistics seeks to introduce express transportation services as the norm to provide time and place utility for mission-critical assets. "Failure to

deliver a critical item when required may be significant in terms of weapon system downtime, customer dissatisfaction, and unnecessary expenditures for stock and storage" (HQ USAF/LGM-2, 1995: 35). A key premise in Lean Logistics is system responsiveness, which depends on the availability of responsive transportation.

Transportation

Transportation supports Lean Logistics in six ways: door-to-door delivery, time definite delivery, reduced order and ship times, in-transit visibility, reduced costs, and reduced mobility footprint (HQ USAF/LGM-2, 1995: 35).

Door-to-Door Delivery. The traditional "mass-logistics" paradigm of the past depended on a node-intensive, intermodal means of transporting personnel, supplies, and equipment. In contrast, Lean Logistics advocates an improved flow of materials and information through logistics processes by substituting velocity (reduced cycle times) for mass (large resource investments), and calls for improving processes to eliminate non-value-adding activities and continuously improve value-adding activities. One way in which Lean Logistics eliminates non-value-adding activities is by using premium transportation. Premium transportation can be defined as express, time definite, guaranteed transportation and is generally more expensive. Premium transportation with door-to-door service provides just-in-time delivery of critical assets with minimum handling and transfers between operating and information systems. This not only provides a seamless flow from the shipper directly to the end user, but also eliminates unnecessary delays and delivery uncertainty (HQ USAF/LGM-2, 1995: 35).

Time Definite Delivery. Time definite delivery transportation services reduce the variability in pipeline in-transit times and provides users with reliable delivery of mission-critical parts (HQ USAF/LGM-2, 1995: 35). This eliminates waste by permitting reduced investments in both cycle and buffer stock inventories. Cycle stock resulting from batch ordering can be maintained at a minimum and be more representative of actual need. In addition, buffer stock used to uncouple operations can be significantly reduced with time definite transportation as operations are tightly coupled and processes are smoothed to allow reliable and continual movement of inventory through the system. Moreover, reliable, time definite transportation of reparable items enables repair facilities to be centralized or regionalized. "Such facilities permit greater economies of scale and eliminate the need for manpower and mobility-intensive base-level repair facilities" (HQ USAF/LGM-2, 1995: 36). Finally, time definite transportation builds increased customer confidence in the logistics system.

Reduced Order and Ship Time. Express transportation services are also able to reduce order and ship times with time saving, streamlined handling and routing procedures. Node reduction eliminates non-value-adding logistics nodes which reduces opportunities for cargo mishandling and damage, and reduces the complexity of asset control and in-transit visibility. For example, the application of return and repair packaging practices, where reparable items can be placed directly into "smart boxes" for return to the depot, eliminates the need to go through the base Traffic Management Office (TMO), a non-value-adding logistics node (HQ USAF/LGM-2, 1996: 10). Additionally,

by ordering smaller quantities more frequently, supply and demand lead times are reduced significantly.

In-transit Visibility. Express transportation services also provide information system support which generates an uninterrupted flow of data to ensure seamless interfaces with shippers and users (HQ USAF/LGM-2, 1995: 35). These same information systems add value by permitting customs clearance and workload planning to begin in advance of cargo arrival, providing continuous in-transit visibility (HQ USAF/LGM-2, 1995: 35). This in-transit visibility capability provides data to the Global Transportation Network (GTN), which integrates it for command and control purposes and to conduct pipeline analysis. Data uses include development of logistics and transportation policy, problem solving, and shipment tracking (HQ USAF/LGM-2, 1995: 35).

Reduced Costs. From an overall cost perspective, "the relative costs of transportation and information are dramatically less than the costs associated with initial inventory purchasing, and inventory carrying costs" (HQ USAF/LGM-2, 1995: 36). Under Lean Logistics, the Air Force buys and maintains fewer spare parts. Buying premium transportation results in savings over initial spares requisitions and storage and handling costs for those items. In addition, reliable express transportation services provide significant cost savings in inventory reduction stemming from reduced variances in order and ship times and more frequent order intervals (HQ USAF/LGM-2, 1995: 36). Inventory quantities previously stocked to make up for the pipeline inefficiencies of the past can be eliminated. In essence, express transportation leverages the relatively low

cost and high reliability of fast transportation against the high cost of buying and maintaining large inventories of spare parts.

Reduced Mobility Footprint. With regard to a reduced mobility footprint, time definite transportation enables deploying units to travel lighter by creating a reliable resupply pipeline. Reliable, express transportation allows deploying troops to travel with less equipment initially with the assurance of being resupplied when needed. In addition, there is no longer a requirement to repair so many spare parts in theater. Thus, expensive bulky equipment and the personnel needed to operate that equipment are not deployed. In essence, a reliable resupply pipeline replaces personnel and equipment during the initial deployment of forces. This results in greater airlift availability, reduced inventories of critical spares, and increased wartime flexibility (HQ USAF/LGM-2, 1995: 36). To implement time-definite delivery service and Door-to-Door Distribution the Air Force will use commercial express carriers of the Civil Reserve Air Fleet (CRAF) during peacetime, and Air Mobility Express (AMX) during contingencies (Morrill, 1994: 9).

Air Mobility Express (AMX)

The cornerstone transportation strategy for supporting Lean Logistics is Door-to-Door Distribution (D^3). D^3 provides time definite, direct and responsive service. D^3 and AMX have their roots in the LOGAIR system implemented in the 1950s. LOGAIR, with its hub and spoke route structure, was "an integrated system of contract aircraft and trucks established to expedite the movement of reparables to, from, and between Air Force bases and their supporting depots" (Morrill, 1994: 9). In essence, LOGAIR can be considered

the pioneer of modern air express systems. Due to budgetary and force structure changes, the DoD formed the LOG EXPRESS Tiger Team to study LOGAIR and its alternatives to determine its effectiveness. The team found that LOGAIR had failed to keep pace with developments in efficient carrier and information management, and consequently was no longer competitive with commercial air carriers in terms of cost, reliability, and visibility. The team determined LOGAIR cost $116 million annually, while D^3, using commercial premium express transportation, cost only $41 million per year (Morrill, 1994: 9). As a result, LOGAIR was disbanded, and rapid movement requirements are now fulfilled by express carriers.

The goal of D^3 is the rapid movement of high value, high priority cargo such as depot level reparables (DLR) within CONUS in one day and to and from the theater within three days (HQ USAF Slide Package, 1995). The speed and visibility afforded by D^3 reduces overall system cost by moving high cost DLRs through the system quickly. "By accelerating reparable item turnover and initial delivery, rapid transportation is substituted for inventory, and becomes, in effect, an inventory multiplier" (HQ USAF/LGM-2, 1995: 36). This allows DoD to purchase and maintain smaller inventories and still effectively support new weapon systems. Although commercial express carriers can handle the majority of DoD's priority cargo transportation needs, there are certain situations when military aircraft are required (movement of engines and certain types of hazardous materials) and preferred (nations with complicated customs clearance procedures).

During a war or contingency operation there may be a need to transport large shipments of DLRs and other critical items on a daily basis. To support this need, the Air Staff Transportation Reinvention Laboratory developed AMX and patterned it after the successful use of the "Desert Express" channel during the Persian Gulf War (HQ USAF Slide Package, 1995). "Desert Express" was designed to provide overnight delivery for high priority, critical item cargo to and from the theater of operations. At the same time, a "European Express" was created to move large amounts of stockpiled spare parts and equipment out of Europe. Both express delivery systems used C-141 aircraft to make a daily round-robin between Charleston and Dhahran or Charleston and Frankfurt. DoD customers used whatever means necessary to transport their cargo to Charleston each day. By the time the official cease-fire was signed on March 10, 1991, the "Desert Express" had moved over 2,038 tons of cargo and the "European Express" had carried 679 tons of cargo (Dungan, 1991: 18). AMX was designed to operate similarly to the "Desert and European Expresses."

AMX is the military adaptation of commercial overnight delivery. It will provide dedicated, wartime, time-definite, two-way (CONUS-theater-CONUS) delivery for high priority sustainment cargo (HQ USAF Slide Package, 1995). High priority sustainment is defined as "critical personnel and cargo that moves to/from the theater ahead of normal sustainment (non-unit) and deploying forces (unit) as determined by supported CINCs" (USTRANSCOM MSG 271453 December 1995). Examples of AMX eligible cargo include critical Class VII(x), VIII, or IX assets such as reparable spare parts, as well as unanticipated, high-demand items that have an immediate impact on combat capability

(Joint Pub 4-01, 1995: IV-7). Each Service will be allocated a certain number of pallet positions to move those items that have been cleared by each Service's respective clearance authority [e.g. USAF: Airlift Clearance Authority (ACA)] and issued a project code.

AMX consists of the express carrier's CONUS infrastructure, Air Mobility Command (AMC) aircraft (CRAF carrier or organic) and a Rapid Theater Distribution System (RDS) for express two-way movement within the theater (Joint Pub 4-01, 1995: III-3). AMC and CRAF will provide daily round-trip direct service between the express carriers CONUS hubs and the designated Aerial Port(s) of Debarkation (APODs) in the theater. AMX is activated during contingencies by USTRANSCOM either concurrently with Chairman of the Joint Chiefs of Staff (CJCS) execution of a CINC Operation Order (OPORD) or at the request of the supported CINCs (Joint Pub 4-01, 1995: IV-7).

AMX Segments. AMX consists of three primary segments. The first segment is the CONUS portion. In this segment, cargo is express delivered to a pre designated hub (commercial or military), consolidated, and assembled on 463L pallets for onward movement. Once consolidated, the cargo is loaded onto an aircraft for express movement to the designated Area of Responsibility (AOR). This enroute leg represents the second segment of AMX. According to HQ AMC, proven modeling techniques such as the Air Deployment Analysis System (ADANS) have shown that AMX can deliver cargo from either a commercial or military hub, to any designated Aerial Port of Debarkation (APOD) in the AOR, within 20 hours using either commercial or military aircraft (HQ AMC Slide Package, 1995).

The third and final segment of AMX is the retrograde or return leg of the system. In this portion, Theater Commanders identify high priority retrograde cargo for return to CONUS. Theater Commanders depend on the inputs of their Service representatives located at the AOR hub to identify CONUS destined retrograde. AMX offers the same 20 hour delivery from the AOR to the CONUS hub. An example of high priority retrograde cargo are critical spares returning to the depot. Upon arrival at the CONUS hub, retrograde items will be placed directly into the cargo backlog for onward movement to the appropriate repair depot. This cargo will be forwarded to its destination by using whatever commercial means available.

AMX Routing Concepts. Currently, AMX is designed to support two routing concepts: AMX-C and AMX-M. AMX-C consists of moving priority cargo to commercial CONUS hubs via commercial express carriers. The carrier, under contract, consolidates loads and then moves them to the theater via AMC procured or AMC organic airlift. The contractor is required to support one daily departure and arrival from their location on a continuing basis and be able to surge to a maximum of two arrivals and departures each day if necessary (HQ AMC/DOJ, 1996: 3). The airframe used is dependent on the hostility level in the AOR. Cargo is limited to small parcel items not to exceed 150 pounds with strict limitations on hazardous cargo (HQ AMC Slide Package, 1995). The aircraft will fly direct to the APOD, either refueling in flight or stopping for fuel at en route support bases.

AMX-M consists of moving large, bulky priority cargo to include engines and hazardous materials via commercial trucks to designated strategic aerial ports and then to

the theater via AMC organic lift (HQ AFMC Slide Package, 1995). The supported CINC has the option to use either the commercial hub, military hub, or both. Upon arrival at the overseas destination, the cargo would be fed into a theater RDS for intratheater distribution within one-day. The seamless lash-up with this distribution system is critical to the success of AMX. The goal for the total transit time of AMX from origin to combat customer is three days or less with a goal for engine movement of no more than six days (HQ USAF Slide Package, 1995). Firm departure times from the hubs will be used to ensure time definite delivery and alert theater CINCs as to when to expect critical parts to arrive in the AOR. In addition, In-transit Visibility (ITV) will be provided from point of origin to AOR.

AMX Benefits. The AMX Concept of Operations provides the necessary guidelines to implement a high priority sustainment and retrograde cargo delivery system during wartime with minimum cargo backlogs at the Aerial Ports of Embarkation (APOEs). During past conflicts such as Korea, Vietnam, and more recently DESERT STORM, " the need for an express airlift channel arose due to the backlog of high priority cargo at the APOEs" (Basham and Evgenides, 1992: 1). Problems determined to cause these backlogs were a shortfall of airlift assets, a lack of a pre-existing plan, and a lack of movement control. AMX was designed to overcome these problems with tighter movement control (CINC involvement and clear participant responsibilities) and by establishing and testing the AMX Concept of Operations prior to the next contingency.

In addition, AMX was designed to radically alter logistics functions by improving and streamlining policy, processes, and management structures in repair, inventory, and

distribution (HQ AFMC Slide Package, 1995). It is a peacetime process developed for wartime support. AMX would provide equal or better operational capability, including mission capable rates, issue effectiveness, and quality. In addition, it is designed to provide time-definite delivery for mission capable parts (MICAPs) and replenishments. Finally, AMX was designed to reduce the mobility footprint with less sustainment support and reduce inventories, minimize handling, and eliminate non-value added nodes at lower costs (HQ USAF Slide Package, 1996).

AMX Assumptions and Constraints. The USTRANSCOM High Priority Sustainment Delivery Study Group identified a number of assumptions and constraints which were thought to apply to the movement of high priority sustainment under AMX (USTRANSCOM MSG 271453 December 1995). Tables 2.3 and 2.4 identify the assumptions and constraints as they are listed in the USTRANSCOM Electronic Message.

TABLE 2.3

AIR MOBILITY EXPRESS ASSUMPTIONS

1. Foreign flag carriers will not be available to expand airlift allocation.
2. Theater reception and onward movement capability are in place.
3. Airlift comes out of CINC apportionment/allocation (except for commercial air).
4. Aircraft slot times and diplomatic clearances will be available.
5. Customs, Immigration, and Agriculture procedures may impact cargo movement.
6. A method exists (including package marking) for distinguishing between high priority and normal sustainment cargo.
7. Increased costs are required, both financial and airframe.
8. A normal channel for sustainment other than high priority will be in-place.
9. Commercial carriers will not fly into a hostile area without CRAF activation.
10. There will be a requirement to continue supporting other CINCs that are not involved in the contingency.

TABLE 2.4

AIR MOBILITY EXPRESS CONSTRAINTS

1. Supply Discipline
2. Port congestion during deployment.
3. Total Asset Visibility is not currently available.
4. Current requisition and supply system.
5. Systems integration is not currently available.

Reparable Assets

The Joint Chiefs of Staff define readiness as: "the ability of forces, units, weapon systems, or equipment to deliver the output for which they were designed" (Joint Pub 1-02, 1994: 221). According to Air Force Doctrine Document 40, " the availability of weapon systems is the best measure of force readiness and the ultimate measure of logistics success" (1994: 12). The availability of weapon systems is a direct result of the logistics assets available to produce fully mission capable aircraft. Aircraft reparable

spares are those assets of primary importance in determining mission readiness and as a result, are used to reflect the performance of our logistics system.

Reparable spare parts can be defined as, "those items that may be economically repaired or reconditioned and returned to a serviceable condition for reuse. The term reparable denotes the logistics status of an item rather than the condition of the item" (Christensen and Ewan, 1985: 1). Unlike high volume, inexpensive consumables, reparable assets are typically characterized as complex, expensive and low demand items. In a typical base supply organization, approximately seventy three percent of all funds spent on supplies is spent on repair cycle assets which account for eleven percent of the total line items in the Air Force inventory (OSD Fact File, 1995: WWWeb). Other terms commonly used to refer to reparables are: recoverables, exchangeables, rotatables, repairables (a broken reparable), and repair cycle assets.

Reparables are repaired under a multi-echelon system. Under the traditional logistics system, reparable assets are repaired at three separate levels: organizational, intermediate, and the depot. Organizational level maintenance is performed at the operating site and consists of routine tasks such as servicing, inspecting, troubleshooting, and repair and replace (RR) (CBO, 1995: 2). Technicians require minimum skills and the equipment used is relatively inexpensive. Intermediate level maintenance is performed at a single site within each combat installation and consists of somewhat more complex tasks such as troubleshooting and repair (CBO, 1995: 2). Technicians require more expertise and the equipment required is expensive. Finally, depot level maintenance is performed at one of five industrial facilities in the CONUS and consists of the most

complex tasks. Tasks involve troubleshooting, repair, major overhauls and modification (CBO, 1995: 2). Technicians require extensive expertise and the use of expensive or rarely used equipment.

Under Lean Logistics, the Air Force has adopted a repair system consisting of only two levels of maintenance (organizational and depot), moving what had previously been intermediate-level tasks to the depots. Despite this reduction in the number of repair sites, the Air Force decided not to increase inventories, but instead, it plans to hold its inventories of spare parts constant (CBO, 1995: 2; GAO, 1996: 1). This is accomplished by emphasizing shortened repair cycles and using commercial express delivery services to compensate for the longer repair pipeline between the customer and the depot, and to ensure just-in-time delivery of spare parts. These reparable spare parts consist of line replaceable units (LRUs) and shop replaceable units (SRUs).

LRUs and SRUs. Aircraft availability can be measured as a direct function of the availability of the aircraft's components: line replaceable units (LRUs) and shop-replaceable units (SRUs). An LRU is defined by Isaacson and Boren as: a component part or assembly "that can be removed from the aircraft and replaced on the flightline" (Isaacson and Boren, 1993: xv). In the indentured relationship among component parts of an aircraft, LRUs are considered component parts of subsystems. "When an LRU fails, base level maintenance replaces the entire unit with an identical unit from base stock" (Gaddis and Haase, 1995: 21). The failed LRU is either repaired at the base level or is identified as Not Repairable This Station (NRTS) and sent to the depot for repair. LRUs are made up of subcomponents called SRUs. SRUs are "typically removed and replaced

during intermediate-level repair" (Abell and others, 1993, xxxi). In the indentured relationship among component parts, one LRU is composed of several SRUs.

USAF Reparable Stockage Policy. Stockage policy determines the amount of inventory held by a particular organization. According to the Joint Chiefs of Staff, it is the "maximum quantity of materiel to be maintained on hand to sustain current operations. It will consist of the sum of stocks represented by operating level and safety level" (Joint Pub 1-02, 1994: 40). Due to the expensive and low demand characteristics of reparable assets, the USAF uses an (S-1, S) inventory policy. "The (S-1, S) inventory policy is a continuous review inventory system where the total stock on-hand plus stock on-order minus the backorders always equals the spare stock level, S" (Christensen and Ewan, 1994: 3). This implies a one-for-one order policy. Stock on-hand is considered stock on the shelf, stock on-order represents stock due in from maintenance or the depot, and a backorder is created when an aircraft "hole" results.

Repair Cycle Demand Level (RCDL) Inventory Model. At the base-level, the Repair Cycle Demand Level (RCDL) inventory model replicates an (S-1, S) inventory policy and is limited to reparable items where customers are required to order on a one-for-one basis (Christensen and Ewan, 1994: 4). The following details the primary features and objectives of the RCDL model as cited by Christensen and Ewan :

> The RCDL model calculates spare stock, or repair cycle demand levels, tailored to individual base repair capabilities as a result of the application of the stockage policies used by base level managers. The RCDL model does not attempt to minimize or maximize any measure of performance. Simply, the stock levels are set to fill pipelines for both the time an asset is in the repair and

> depot-to-base replenishment cycles, with a set safety quantity added for protection against stockouts. (1994: 4)

As stated, the RCDL model uses an item approach to stock reparable spare parts. Using an item approach, inventory levels are set to stock the average spares required for the pipeline plus safety stock, where a constant "k" protection factor is applied across all items. In addition, spares are maintained to achieve a predetermined customer service level. The number of spares for an item is determined by using simple formulas that balance the costs of holding inventory, ordering, and stockout on an item-for-item basis (Sherbrooke, 1992: 3).

The Repair Cycle Demand Level inventory model incorporates several quantities: base repair cycle quantity (RCQ), order and ship time quantity (OSTQ), not repairable this station/condemned quantity (NCQ), safety level quantity, and a constant factor (K) based on item cost to compute the necessary stock on hand to meet current demand (Christensen and Ewan, 1994: 4). RCQ and NCQ represent the necessary stock to fill the repair cycle pipeline, OSTQ fills the depot-to-base replenishment pipeline, and SLQ compensates for the fact the RCDL model assumes demand is constant (Christensen and Ewan, 1994: 4). The RCDL model for computing the base reparable stock level (s) is shown in equation (1):

$$s = RCQ + OSTQ + NCQ + SLQ + K \quad (1)$$

The individual quantities of the RCDL model are computed as follows:

$RCQ \;= DDR * PBR * RCT$

$OSTQ = DDR * (1 - PBR) * OST$

$NCQ \;= DDR * (1 - PBR) * NCT$

$SLQ \;= C * [3 * (RCQ + OSTQ + NCQ)]^{1/2}$

K = .5 if unit cost is greater than \$ 750.00, or .9 if unit cost is \$ 750.00 or less

Table 2.5 presents the RCDL model quantity definitions and Table 2.6 presents the formulas for calculating each component of the RCDL model.

TABLE 2.5

REPARABLE DEFINITIONS (Pohlen, 1995)

Term	Definition
DDR	Average daily demand rate for an item as calculated in the SBSS.
PBR	Average fraction of assets which can be repaired on base. PBR is a function of authorized repair levels, available technician skills, etc.
NRTS	Average fraction of assets which cannot be repaired on base (1-PBR).
RCT	Average amount of time that it takes to repair an item on base, given that it is base repairable. Excludes OP time.
RET	Time it takes to ship an unserviceable reparable carcass from the base to the next higher level of repair.
DRT	Average amount of time it takes a depot to repair a specific type of asset.
OST	Average time it takes to transmit a stock replenishment requisition between a given base and source of supply, plus the depot response time for packing and crating the serviceable asset, plus the shipment transit time from the depot to the base.

TABLE 2.6

RCDL INDIVIDUAL COMPONENT FORMULAS (Christensen and Ewan, 1994: 5)

Quantity	Definition	Formula
DDR	Daily Demand Rate	Cumulative Recurring Demands / Max of (180 Days, Current Julian Date - DOFD)
PBR	Percent Base Repair	Number Repaired Units X 100 / Sum of Units Repaired, NRTS, Condemned
RCT	Repair Cycle Time	Sum Repair Days / Number Repaired
NCT	NRTS Condemned Time	Sum NRTS/Condemned Stock / Number NRTS/Condemned
OST	Order and Ship Time	Sum of Depot to Base Ship Days / Number of Receipts
C	C Factor (Number of Std Deviations to Protect Against Stockout)	N/A

The item approach used to stock reparable spare parts at the base has been proven to be an inefficient method (Sherbrooke, 1992: 3). Because it sets stockage levels on an item for item basis, the richness of stock levels at all bases may far exceed the assets available (Miller and Abell, 1995: 13). In other words, it is possible to have the sum of stock levels at all locations exceed the total number of spares in the system. The item approach fails to consider the total investment in the system. It also fails to consider the impact of spares levels on weapon systems or system wide aircraft availability goals. Finally, the item approach does not relate readiness or requirement levels to the set spares levels at each base. As the necessity to reduce costs, lean inventories, and maintain weapon system readiness continue, the Air Force is transitioning to a systems approach to determine reparable spare stock levels.

Systems Approach

According to Craig C. Sherbrooke, inventory stockage levels for all items should be set to optimize system-wide performance objectives. The “mix of spares” should be managed to find the right mix based on available resources to obtain the best possible performance of the logistics system (1992: 2-7). This directly contrasts traditional thought where setting “optimal” inventory stock levels on an item-by-item basis is the norm. A systems approach to inventory management considers all the elements of the logistics network to include all items, all locations, and all echelons. Limited resources (inventory or dollars) are allocated based on where they would generate the greatest expected improvements to overall system performance. Assets are distributed in a manner that supports an operational units’ aircraft availability goals.

Expected Backorders. According to T.J. O’Malley “ the Air Force uses expected backorders (EBOs) at base level and the relationship of those EBOs to aircraft availability as primary measures of system level performance” (1996: 4). An expected backorder is defined as “the long run average number of shortages experienced given a particular stock level and the expected pipeline quantity” (Pohlen, 1996). Given that the stock level is S and that the number of units in resupply is Poisson distributed with a mean pipeline quantity ($\lambda\tau$), Sherbrooke outlines the equation for expected backorders as follows:

$$EBO(S) = \sum_{X=S+1}^{\infty} (X - S)\Pr(DI = X)$$

This computation is the equivalent of summing the number of backorders (X-S) multiplied by the probability of having X backorders (Sherbrooke, 1992: 25). When

using a systems approach to setting "optimal" inventory stock levels, expected backorders together with item costs are examined in a technique called marginal analysis.

Marginal Analysis. "Marginal analysis is a mathematical technique that enables the Air Force to take expected backorder values and determine the implications on aircraft availability of adding the next unit of an item to a specific inventory system" (Gaddis and Haase, 1995:33). In other words, for every stockage decision, marginal analysis considers the systems implications of adding the next unit of an item to inventory to get the "biggest bang for the buck". Additional units of an item are bought in diminishing order of their benefit-to-cost ratio (BCR) until either funds are exhausted or some system-wide performance objective is achieved (Sherbrooke, 1992: 31). The following is an example of how marginal analysis is used to purchase two items (Sherbrooke, 1992: 30):

> Step 1 - Determine the pipeline quantity for each item. Step 2 - Obtain the cost for each item. Step 3 - Calculate the expected backorders for each item at various stock levels. If there is a budget constraint, stop where the stock level multiplied by the cost equals the budget constraint. Step 4 - Calculate the BCR for each stock level. This is accomplished using the following equation:

$$BCR = \frac{[EBO(S - 1) - EBO(S)]}{C}$$

Where:

EBO = Expected Back Order
S = Stock Level
C = Cost of Item

> Step 5 - Select additional items in diminishing BCR order.

Item 1 Cost = $5,000		
S	EBO(S)	BCR
0	1.000	
1	.368	.126
2	.104	.053
3	.023	.016
4	.004	.004
5	.001	
6	.000	
7	.000	

Item 2 Cost = $1,000		
S	EBO(S)	BCR
0	4.00	
1	3.018	.982
2	2.110	.908
3	1.348	.762
4	.782	.567
5	.410	.371
6	.195	.215
7	.085	.111

Shopping List				
Allocation	S1	S2	∑SiCi	∑EBOs
0	0	0	0	5.000
1	0	1	1	4.018
2	0	2	2	3.110
3	0	3	3	2.348
4	0	4	4	1.782
5	0	5	5	1.410
6	0	6	6	1.195
7	1	6	11	.563
8	1	7	12	.453
9	2	7	17	.189

Figure 2.1 Marginal Analysis LRU Shopping List

Figure 2.1 indicates the results of the marginal analysis where seven units of item 2 and two units of item 1 were bought for a total cost of $17,000. The resulting system EBO is .189 compared to 5.000 before any stock is purchased. The systems approach uses expected backorder values to answer questions such as: "How can we ensure that 95% of our scheduled aircraft flights will not be delayed for a lack of spare parts?" (Sherbrooke, 1992: 2).

Recognizing the advantages of the systems approach, the technique of Readiness Based Leveling (RBL) was adopted to replace the RCDL model for allocating spares. Unlike the RCDL model, RBL is a multi-echelon system which computes both base and depot stock levels simultaneously (Reynolds and others, 1995: 6). RBL uses the Multi-Echelon Technique for Recoverable Item Control (METRIC) algorithm to allocate the worldwide spares requirement among Air Force Bases and the depot to minimize worldwide base expected backorders (Reynolds and others, 1995: 6). Within METRIC, the marginal analysis technique is used to allocate requirements to bases or the depot which results in the greatest benefit system wide, as measured by the decrease in expected backorders (Reynolds and others, 1995: 6). This decrease in expected backorders translates into a decrease in "holes" in the aircraft and thus, impacts aircraft availability rates (Sherbrooke, 1992: 38). In short, by minimizing expected backorders, aircraft availability is maximized.

Aircraft Availability

Aircraft availability is a direct result of the efficiency and responsiveness of the logistics pipeline. An airlift wing's aircraft availability rate is defined as the probability of assigned aircraft being available to perform their intended combat mission based strictly on the factors of logistics support. These factors include the level of on-hand assets, order and ship times, and the available repair capability. Aircraft availability does not mean an aircraft is fully mission capable (FMC). To clarify, a reparable asset can be physically located on the base and aircraft availability is at 100%; however, if maintenance has not yet placed the asset on the aircraft, the aircraft is not considered

FMC. One definition of aircraft availability states, "an aircraft is defined to be available if it is not waiting for a component to be repaired or be shipped to it" (Abell and others, 1993: xxvii). More specifically, Isaacson and Boren define aircraft availability as:

> An aircraft is considered to be unavailable if it is missing any of its LRUs (i.e. if it has a hole for an LRU). At the conclusion of pipeline segment processing, we have for each LRU the total number tied up in the base pipeline (i.e. in the base's administrative, maintenance, awaiting parts, and on-order segments). The number of holes for a given LRU is simply the amount by which the base pipeline exceeds the base stock level. If the base pipeline is less than the base stock level, there are no holes. (Isaacson and Boren, 1993: 33)

Moreover aircraft availability can also be represented mathematically. Sherbrooke outlines the mathematical equation for aircraft availability as follows:

> Availability (A), the expected percent of the aircraft fleet that is not down for any spare is given by the following product:
>
> $$A = 100\prod_{i=1}^{I}\left\{1 - EBO_i(s_i)/(NZ_i)\right\}^{Z_i}$$
>
> with the constraint that $EBO_i(s_i) \leq Nz_i$ for every item *i*. Z_i is the number of occurrences on an aircraft of the *i*th LRU (quantity per aircraft) and N is the number of aircraft. The logic is that there are NZ_i locations of LRU *i* in the fleet of aircraft, the probability of a hole in any of these locations is $EBO_i(s_i)/(NZ_i)$ (the probability cannot exceed one). An aircraft will be available only if there is no hole for any of the Z_i occurrences of LRU *i* (which accounts for the exponent), or for any other LRU (which accounts for the product over *i*). (Sherbrooke, 1992: 38)

In the equation above, Sherbrooke uses the symbol $EBO(s_i)$ to represent the expected number of backorders (expected number of unfilled demands), given a specific stock level and expected pipeline quantity for a particular LRU. An EBO represents a

"hole" in an aircraft, indicating a failed LRU which grounds the aircraft. To simplify, the aircraft availability formula gives the probability that the aircraft is not unavailable due to broken parts. As can be clearly demonstrated by Sherbrooke's formula, minimizing the sum of backorders is equivalent to maximizing aircraft availability.

Logistics Pipeline

To minimize the number of backorders, repair cycle assets must be available when needed. Without maintaining large stocks of inventory at base level, Lean Logistics focuses on rapidly repairing and flowing repaired parts through the pipeline in direct response to demands. To accomplish this, Lean Logistics centralizes inventories, leans base levels, employs express transportation to achieve response and speed, and dramatically improves processes. According to T. J. O'Malley, "the major principle of Lean Logistics is the reduction of transportation and repair times, a substitution of velocity of items through resupply for mass of inventory" (1996: 8). The results of timely shop repair and expedited movement of reparables in effect maximizes aircraft availability.

The logistics pipeline can be defined as: "a system of supply, repair, and transportation activities that together form a distribution network for unserviceable and serviceable spares" (Pohlen, 1996). Pipelines are typically characterized by their length, diameter, volume, and routing (Bond and Ruth, 1989: 5). The length of the pipeline represents the time it takes to move reparable assets from one point in the system to another. The diameter of the pipeline represents the maximum number of assets that may flow through the pipeline or be held in any one segment of the pipeline. The volume

represents the quantities of assets in the system and the routing indicates the movement of items through various processes of the logistics system (Bond and Ruth, 1989: 5). Together, these characteristics form the USAF reparable pipeline which can be broken down into three primary segments: 1) base level, 2) depot level, and 3) transportation.

Base Level. When an aircraft reparable part fails, base level maintenance personnel identify the failed item and order a replacement item from base supply. When supply issues the item to maintenance, the repair cycle time begins. The failed part is then sent to maintenance to determine whether or not the asset is repairable at base level. If the failed item can be repaired at the base, it immediately enters the base's maintenance system and is repaired. The repaired item is then turned in to supply where it becomes part of the supply stock, replacing the previously issued item.

If the failed item is not base repairable, it is determined to be NRTS and begins the process characteristic of the reparable asset pipeline. The failed asset is sent from base maintenance to base supply for shipment to the depot, the second echelon of the two echelon system. At the time of the NRTS turn-in to supply, a requisition to the depot is made to bring the base stock level back to equilibrium for the original item issued (Christensen and Ewan, 1994: 14). The depot then sends a replacement unit to the base, provided a serviceable spare is available and if not, as soon as one is available. Thus, resupply of spares assets to the base supply organization is provided by base maintenance when repair capability for a failed part exists on the base and from the depot when the failed part is identified as NRTS.

When a serviceable asset is not available at base supply, another set of actions occur. If an unserviceable asset can be repaired by maintenance, it is reinstalled on the aircraft (repair and return) and no demand for a part is made on supply. However, if the unserviceable asset is not base repairable and determined to be NRTS, then a demand for a part is made on supply. In this example, a requisition for a serviceable asset is sent to the depot and the unserviceable asset is sent to the depot for repair (Christensen and Ewan, 1994: 15). Under Lean Logistics, emphasis is placed on expedited evacuation of reparables by bases to the depots. Figure 2.2 depicts a visual representation of the reparable pipeline as it currently exists. The top half represents the depot repair cycle, while the lower half represents the base repair cycle. Figures 2.3 and 2.4 depict the current repair cycle time and lean repair cycle time, respectively.

Reparable Pipeline

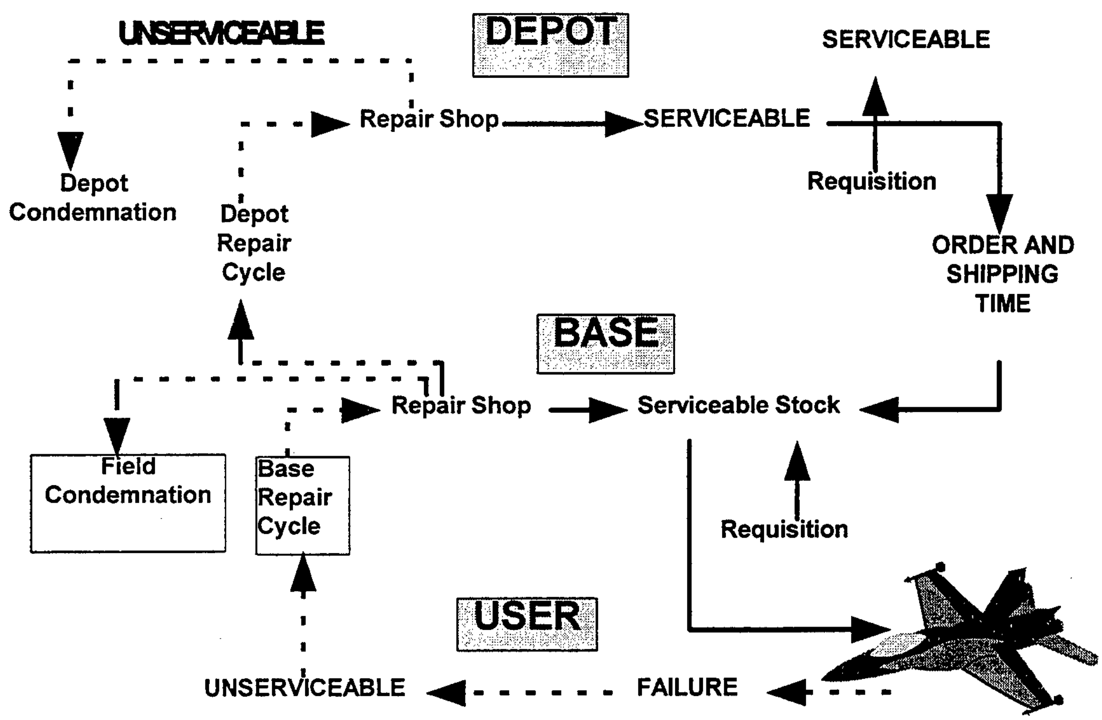

Figure 2.2 Reparable Pipeline (Pohlen, 1996)

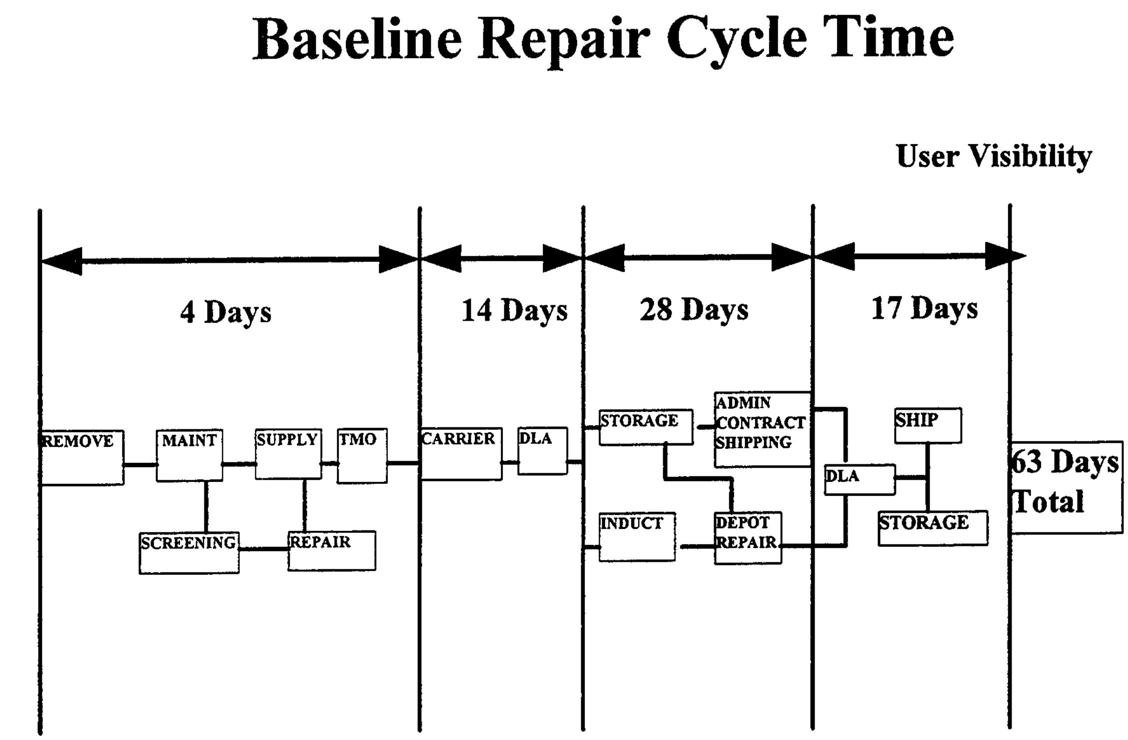

Figure 2.3 Current Repair Cycle Time (HQ USAF/LGM-2, 1995: 8)

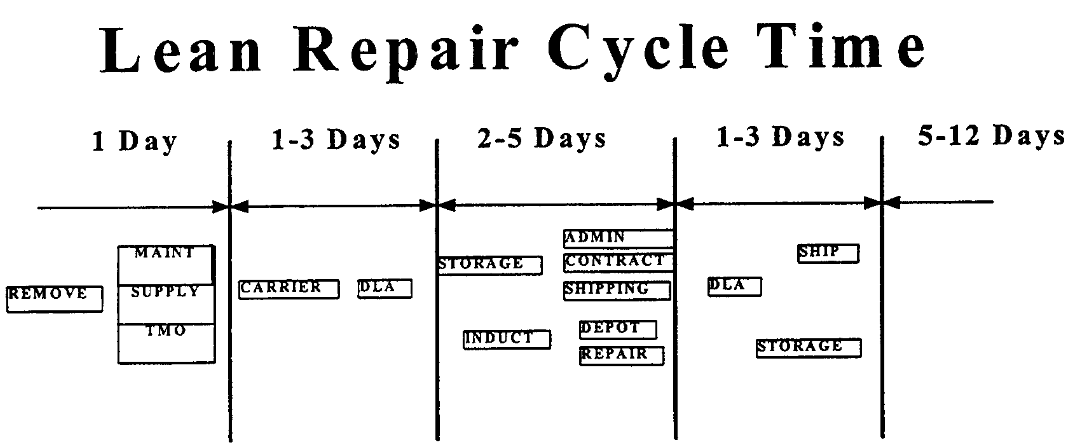

Figure 2.4 Lean Repair Cycle Time (HQ USAF/LGM-2, 1996: 3)

Depot Level. Currently, depot level repair capability is provided by five Air Logistics Centers (ALC's) located at Mc Clellan AFB, CA., Hill AFB, UT., Kelly AFB, TX., Warner Robbins AFB, GA., and Tinker AFB, OK. Each repair facility provides similar supply and maintenance functions consisting of weapon systems overhaul and repair or remanufacture of reparable assets. Once an unserviceable asset is identified at the base level as NRTS, it is sent to the depot repair facility and is considered to be retrograde. Once the asset is repaired at the depot, it is returned to depot serviceable stock until a demand is placed for that item. Once the depot receives a requisition for the item, the depot sends it to the requesting base.

Under Lean Logistics, "a consolidated serviceable inventory (CSI) is used to provide a central repository for serviceable assets to support unit/field operations" (HQ USAF/LGM-2, 1996: 12). The CSI is managed jointly with the assets in work-in-process (WIP) at the depot. WIP is the "expected number of assets being repaired in the shop. It is the total demands on the depot per day multiplied by the depot repair process days" (Mc Cormick, 1996: 12) Together, the CSI and the WIP form the working level (WL). The WL is the number of assets (in repair plus serviceable) needed in the depot system to support operating units in the field given transport times to and from the depot and the variability of failures in the field" (Mc Cormick, 1996: 13; HQ USAF/LGM-2, 1996: 12). In other words, the CSI attempts to reduce depot delay time and protect flightline customers from the variability in the system (HQ AFMC, 1996: 1). This variability results from time uncertainty in the repair process and uncertainty in customer demands themselves. When a customer places a demand on the CSI, a serviceable asset

is shipped to the customer. To maintain the "flow" of assets, the depot repairs assets to replace those that are shipped from the CSI to fill customer demands (HQ AFMC, 1996: 9).

In addition to the CSI, the depot maintains a Consolidated Reparable Inventory (CRI). The CRI is usually located in, or near the repair shops and is designed to contain enough reparable assets on the shelf to prevent the variability in the return pipeline from impacting the depot's ability to generate serviceable assets when they are needed (HQ AFMC, 1996: 15). The CRI is computed as the depot daily demand rate multiplied by the retrograde process days (Mc Cormick, 1996: 13). In essence, the flightline customer is protected from variability by three separate buffers: the CRI, the CSI, and the base supply. Figure 2.5 demonstrates the relationship between the customer and these inventory buffers.

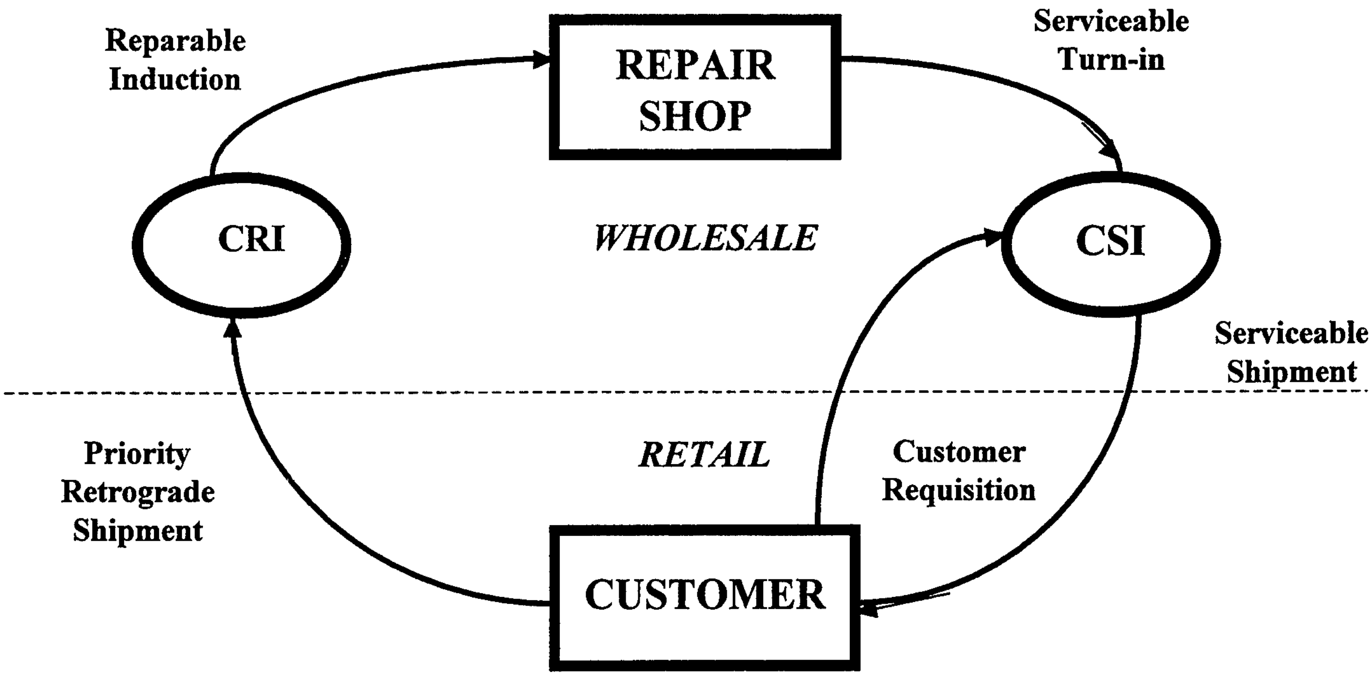

Figure 2.5 Customer - Inventory Relationship

"Depot maintenance accounts for a large share of total assets held in the pipeline and for a significant portion of the pipeline time used while assets are repaired and returned to field usage" (Bond and Ruth, 1989: 96). A major cause of delay of reparable assets in the pipeline is the use of batch processing with quarterly negotiations. Maintenance and supply forecast component demands and repairs on a quarterly basis and use these quantities as the starting point for repair negotiations. Negotiations allow for capacity, labor, or skills constraints, maintenance efficiencies, operational priorities, funding, and a host of other considerations (O'Malley, 1996: 9). The negotiated quantity then becomes the repair target for that quarter and maintenance works to achieve that target. This process results in overestimating or underestimating demands which leads to more or less repairs than needed. In addition, items are typically repaired in a batch mode which tends to produce serviceable assets later in the quarter than needed.

Traditionally, batch processing has been the preferred method for the repair and remanufacture of reparables. Batch production processes are used to collect small lot sizes of similar products which are then processed in batches with short production runs using essentially the same sequence of operations (Evans, 1993: 128). However, for different types of reparables, shop flow can be quite diverse, resulting in a vast range of repair times. As a result, much of the Air Force's initial attention in implementing Lean Logistics focuses on the reparable/serviceable pipeline and efforts to reduce days in the cycle through various initiatives (HQ USAF/LGM-2, 1995: 7). Initiatives such as tightened repair and manufacturing and priority repair procedures are designed to streamline and eliminate redundant repair processes.

Priority repair procedures incorporate repair on demand to replace the previously used batch process repair procedures with quarterly negotiations. Repair on demand is repairing assets based on real-time customer demands. For example, each time a customer demand is received at the depot, the number of in-work and serviceable assets on-hand is compared to the depot working level for that particular NSN. Any shortfall that exists between the working level and the on-hand assets is by definition a repair requirement. If there is no shortfall, there is no repair requirement. If there is a shortfall, a repair requirement is generated, thus depot maintenance repairs the asset based on real-time actual customer demands (O'Malley, 1996: 8). By tightening repair and manufacturing, management is simplified, non-value added actions and indirect labor are reduced, and repair-on-demand can be implemented with small amounts of systemwide

stocks such as the CRI and CSI. As a result depot and base repair flow times, quality, and surge capability are improved (Pyles, 1993: 9).

Transportation. Transportation serves to link the bases and the depots within the reparable asset pipeline. Moving parts fast literally translates to needing fewer parts in the system. Express transportation leverages the relatively low cost and high reliability of fast transportation against the high cost of buying and maintaining large inventories of spare parts. With fast transportation, reparable assets ordered from the depot will be shipped to the requisitioning base in one to three days during peacetime and wartime operations with the implementation of AMX. Normally CONUS bases will receive their assets within one to two days, while overseas shipments may require up to three days.

Express transportation service can have a significant impact on spares availability at the base. Depot repair time impacts order and ship time, which impacts the number of reparable spares available in the pipeline, which ultimately impacts the expected number of backorders at the base and aircraft availability. By reducing the depot repair time and order and ship time, speed replaces inventories, which reduces costs and improves customer support to the warfighter.

Summary of Lean Logistics

Lean Logistics is an Air Force program designed to incorporate state-of-the-art business practices into our logistics processes. The objective of Lean Logistics is to streamline policies, processes, and management structures that drive costs in Air Force infrastructures. Achieving these objectives will enable the Air Force to provide strong, less costly weapon system support to operational users in both peace and war. With

respect to transportation and repair, Lean Logistics objectives are achieved through increased system responsiveness, reduced inventory investment, node reduction, service reliability, logistics pipeline integration, centralized and priority repair, and differentiated levels of service and pricing. In addition, the development of Air Mobility Express facilitates Lean Logistics objectives by taking a peacetime process and adapting it to wartime use.

Performance Analysis Models

This section describes the models that will be used to perform the Lean Logistics performance analysis using Air Mobility Express in a wartime scenario. Three models are described: the Multi-Echelon Technique for Recoverable Item Control (METRIC) Model, the Dynamic Multi-Echelon Technique for Recoverable Item Control (Dyna-METRIC) Model (versions 4.6 and 6.4), and the Aircraft Sustainability Model (ASM). Although the METRIC model is not used directly to perform the analysis in this thesis, METRIC is the basis for the development of the two primary models which are used: Dyna-METRIC and ASM. Thus, a discussion of METRIC is warranted. The following discussion will provide a description of each model, its capabilities, underlying assumptions, and uses. Table 2.7 provides a brief comparison of the models to follow.

TABLE 2.7

MODEL COMPARISON

MODEL	METRIC	Dyna-METRIC 4.6	Dyna-METRIC 6.4	ASM
Type of Model	Analytical	Analytical	Simulation	Analytical
Item	Multi	Multi	Multi	Multi
Location	Multi	Multi	Multi	Multi
Echelon	Multi	Multi	Multi	Multi
Indenture Relationship	Single	Multi	Multi	Multi
Demand Environment	Stationary	Dynamic	Dynamic	Dynamic
Objective Function	Minimize Expected Backorders	Minimize EBO Maximize Aircraft Availability	Minimize EBO Maximize Aircraft Availability	Minimize Expected Not Mission Capable Supply
Performance Measures	Expected LRU Backorders	Expected Backorders by Part, Aircraft Availability Rate	Expected Backorders by Part, Aircraft Availability Rate	Expected Backorders by Part, Aircraft Availability Rate
Outcome Analysis	Requirements	Requirements Assessment	Assessment	Requirements

Multi-Echelon Technique for Recoverable Item Control (METRIC) Model

METRIC was formulated by Craig C. Sherbrooke of the RAND Corporation in 1966 and was the first multi-item, multi-echelon, reparable inventory model ever proposed for implementation (Sherbrooke, 1968: 123). METRIC considers only single indenture items (LRUs) and has a system wide objective of minimizing expected backorders (Sherbrooke, 1992: 47). METRIC is multi-item in that it considers the procurement and placement of more than one item across all bases and the depot. It is multi-echelon in that it considers at least two echelons of supply and repair, the bases and

the depot. METRIC's primary advantage over the RCDL model is that it uses a systems approach rather than an item approach to project the optimal number of spare parts to buy for each item. Spare parts are bought to achieve a desired aircraft availability rate within a budgetary constraint. Sherbrooke describes METRIC as:

> ...a mathematical model translated into a computer program, capable of determining base and depot stock levels for a group of recoverable items; its governing purpose is to optimize system performance for specified levels of system investment. METRIC is designed for application at the weapon-system level, where a particular line item may be demanded at several bases and the bases are supported by one central depot. (Sherbrooke, 1968: 123)

METRIC estimates spares requirements based on the mathematical assumptions contained in Table 2.8.

TABLE 2.8

METRIC ASSUMPTIONS (Sherbrooke, 1968: 126-131; Pohlen, 1996)

1. The system-wide objective is to minimize the sum of the expected backorders for all reparable items at all bases for a specific weapon system. A backorder is defined as a "hole" in an aircraft, indicating a failed LRU which grounds the aircraft.
2. The (S-1, S) inventory policy is appropriate for every item at every echelon. There is no batching of units for repair or for resupply requests. However, some batching of repair at the depot is modeled by including an average "waiting" time into the average depot repair time.
3. Each item has a logarithmic Poisson demand process.
4. Demand is stationary. The number of aircraft operated and their flying hours remain fairly constant over the near-term.
5. The base is resupplied from the depot, not by lateral resupply from another base.
6. The decision as to whether a base repairs an item does not depend on the stock levels or workload. A base will repair an item if they are capable and if an item is AWP, the base requisitions parts as appropriate from the depot.
7. The system is conservative. There are no asset condemnations.
8. Depot repair begins as soon as the part arrives from the base.
9. Demand data from different bases can be pooled.
10. Reparable items have equal essentialities, that is, the relative backorder cost for all items is the same

Since the objective of METRIC is to minimize the sum of expected backorders across bases, the expected backorder calculation is very important. Expected backorders are determined based on given stock levels and pipeline quantities. There are five stages in the METRIC solution process. The first stage consists of calculating the average time between a base request for a resupply from the depot and the base receipt of the item. In this calculation, depot delay time and depot repair time are considered. In stage two, expected backorders, as a function of the base stock, are computed for each level of depot stock and each base.

In stage three, a marginal analysis is performed to optimally allocate the (first, second, third, ...) units of depot stock to the bases in order to minimize the sum of expected backorders at all bases. This marginal analysis is performed for each level of depot stock and places the next unit of stock where the biggest "bang for the buck" will be realized. In stage four, a table is constructed identifying the expected backorders by item given the depot stock level, and the total stock across all bases, under optimal allocation (Klinger, 1994: 17-19). The diagonal entries in this table represent total system-wide stock for an item. For each stock level, the minimum expected system backorders can be identified and corresponding stock allocations recorded (Sherbrooke, 1968: 133).

The final stage considers all items. Another marginal analysis is performed to determine the optimal allocation of all items across all bases and the depot. The allocation procedure ends whenever the investment constraint is just exceeded or the expected backorders are just less than a specified target value (Sherbrooke, 1968: 134). With the completion of this marginal analysis, METRIC results in a "shopping list" of what items should be purchased. The following is an example of how the METRIC model can be used to demonstrate the trade-off between express transportation services, inventory levels, and achieved aircraft availability subject to a budget constraint.

METRIC Example. This example considers two items at a single base with 18 aircraft assigned. Item 1 costs $7,500 with a quantity per aircraft (QPA) of one and item 2 costs $1,000 with a QPA of one. The METRIC algorithm is used to perform a marginal analysis from which a "shopping list" is produced of what items should be purchased

based on a $ 20,000 budget constraint. The marginal analysis is performed twice based on two separate order and ship times (current and lean). Table 2.9 contains the input data used to produce the results presented in tables 2.10 through 2.13.

TABLE 2.9

METRIC EXAMPLE - INPUT DATA

Parameters	Current OST		Lean OST	
	Item 1	Item 2	Item 1	Item 2
Cost (In Thousands of $)	7.5	1.0	7.5	1.0
Average Annual Demand at Base j (Demands/Year)	55	55	55	55
Average Repair Time at Base j (In Years)	.02	.02	.02	.02
Probability of Repair at Base j	.75	.75	.75	.75
Average OST from Depot to Base j (In Years)	**.173**	**.173**	**.033**	**.033**
Average Annual Demand on the Depot (Demands/Year)	13.75	13.75	13.75	13.75
Average Repair Time at the Depot (In Years)	.15	.15	.15	.15

TABLE 2.10

MARGINAL ANALYSIS - CURRENT OST

EXPECTED BACKORDERS FOR A DEPOT STOCK LEVEL OF ZERO

Item 1 Cost = $7,500		
S	EBO(S)	BCR
0	5.2663	
1	4.2714	.1326
2	3.3038	.1290
3	2.4077	.1195
4	1.6373	.1027
5	1.0324	.0807
6	.6018	.0574
7	.3241	.0370
8	.1615	.0217
9	.0746	.0116
10	.0320	.0057

Item 2 Cost = $1,000		
S	EBO(S)	BCR
0	5.2663	
1	4.2714	.9948
2	3.3038	.9676
3	2.4077	.8961
4	1.6373	.7704
5	1.0324	.6049
6	.6018	.4307
7	.3241	.2777
8	.1615	.1626
9	.0746	.0869
10	.0320	.0425

TABLE 2.11

SHOPPING LIST - CURRENT OST

Allocation	S1	S2	ΣSiCi	ΣEBOs
0	0	0	0	10.5326
1	0	1	1	9.5377
2	0	2	2	8.5701
3	0	3	3	7.674
4	0	4	4	6.9036
5	0	5	5	6.2987
6	0	6	6	5.8681
7	0	7	7	5.5904
8	0	8	8	5.4278
9	1	8	15.5	4.4329

With an OST of .173 years, the results of the marginal analysis indicate eight units of item 2 and one unit of item 1 were bought for a total cost of $15,500. The resulting EBO

is 4.4329 compared to 10.5326 before any stock is purchased. The attained aircraft availability is 76% based on equation 2:

$$A = 100\prod_{i=1}^{I}\left\{1 - EBO_i(s_i)/(NZ_i)\right\}^{Z_i} \tag{2}$$

TABLE 2.12

MARGINAL ANALYSIS - LEAN OST

EXPECTED BACKORDERS FOR A DEPOT STOCK LEVEL OF ZERO

Item 1 Cost = $7,500		
S	EBO(S)	BCR
0	3.3413	
1	2.3766	.1286
2	1.5303	.1128
3	.8815	.0865
4	.4527	.0572
5	.2078	.0327
6	.0856	.0163
7	.0319	.0072
8	.0108	.0028
9	.0034	.0010
10	.0010	.0003

Item 2 Cost = $1,000		
S	EBO(S)	BCR
0	3.3413	
1	2.3766	.9646
2	1.5303	.8464
3	.8815	.6488
4	.4527	.4288
5	.2078	.2450
6	.0856	.1221
7	.0319	.0537
8	.0108	.0211
9	.0034	.0075
10	.0010	.0024

TABLE 2.13

SHOPPING LIST - LEAN OST

Allocation	S1	S2	∑SiCi	∑EBOs
0	0	0	0	6.6826
1	0	1	1	5.7179
2	0	2	2	4.8716
3	0	3	3	4.2228
4	0	4	4	3.794
5	0	5	5	3.5491
6	1	5	12.5	2.5844
7	1	6	13.5	2.4622

With an OST of .033 years, the results of the marginal analysis indicate six units of item 2 and one unit of item 1 were bought for a total cost of $13,500. The resulting EBO is 2.4622 compared to 6.6826 before any stock is purchased. The attained aircraft

availability is 86%. When comparing the results of each marginal analysis, it is clear that a reduced order and ship time (resulting from express transportation services) leads to fewer items being stocked at a lower overall cost and higher aircraft availability. Table 2.14 is a summary of the results.

TABLE 2.14

SUMMARY OF TRANSPORTATION, INVENTORY, AND AIRCRAFT AVAILABILITY RESULTS

	Current OST	Lean OST
Number of Item 1 Stocked	1	1
Number of Item 2 Stocked	8	6
Cost	$15,500	$13,500
System Wide EBO	4.4329	2.4622
Aircraft Availability	76%	86%

According to Reynolds and others, "METRIC has been used by the Air Force since the mid 1960s for requirements determination. It was also used in the Air Force Recoverable Central Leveling (DO28) System and until 1992 was used to allocate the worldwide requirement to the bases" (Reynolds and others, 1995: 12). Most recently, the METRIC algorithm is being used as the basis of the Readiness Based Leveling (RBL) stock leveling approach (Reynolds and others, 1995: 13).

In addition, the Army uses an improved version of METRIC called SESAME (Selected Essential-Item Stockage for Availability Method). "SESAME is used for initial spares budgeting in a three-echelon, two-indenture calculation and for item procurement in a two-echelon, two-indenture calculation" (Sherbrooke, 1992: 200). In the past SESAME was primarily used by the Army for communications and missile equipment;

however, as of June 1990, it has been used for all classes of equipment (Sherbrooke, 1992: 200).

Dynamic Multi-Echelon Technique for Recoverable Item Control (Dyna-METRIC)

Dyna-METRIC was developed by R. J. Hillstead and M. J. Carrillo of the RAND Corporation in 1980 as an analytic model to assess worldwide logistics support for aircraft components, including depot-theater interactions (Isaacson and others, 1988: 1). The model can be operated in two modes: the forward mode and the backward mode. The forward mode is used to determine spare parts and aircraft availability, while the backward mode identifies a list of problem parts whose support resources and processes constrain aircraft availability (Isaacson and others, 1988: 8-10).

Dyna-METRIC allows the user to assess how diverting spares from one theater to another might affect support in both theaters, or how repair and transportation processes, stock levels, cannibalization policies, and wartime plans interact to affect combat capability (Isaacson and others, 1988: 1). Dyna-METRIC primarily focuses on the dynamic flying hour environment representative of wartime scenarios, and attempts to model spares requirements based on the uncertainty of demands generated during wartime flying activity (Sherbrooke, 1992: 184). Currently, there are several versions of Dyna-METRIC, both analytic and simulation based.

Dyna-METRIC version 4.6 is a multi-item, multi-indenture, and multi-echelon model. It is multi-indenture in that it considers LRUs that are composed of SRUs which are composed of sub-SRUs. Sub-SRUs include "bits and pieces that are consumed during SRU repair as well as other components that may be repaired either locally or at a

higher echelon" (Isaacson and others, 1988: 4). It is multi-echelon in that it models the logistics component support system as a five-echelon hierarchical structure. The five echelons include: flight lines, local base repair shops, centralized intermediate repair facilities (CIRFs), depots, and various suppliers of components (Isaacson and others, 1988: 5).

The primary advantage of Dyna-METRIC is its ability to model the wartime logistics system by considering "time varying demands". For example, Dyna-METRIC combines each component's dynamic demands and repair times to estimate the expected pipeline quantity for each pipeline segment (Isaacson and others, 1988: 8). In addition, Dyna-METRIC provides logisticians with five kinds of information to improve wartime logistics support within a single theater. These are:

1. operational performance measures
2. effects of wartime dynamics
3. effects of repair capacity and priority repair
4. problem detection and diagnosis
5. spares requirements (Isaacson and others, 1988: 1)

Based on these capabilities, logisticians can use Dyna-METRIC to evaluate "current and future logistics support in a changing environment with limited resources, to develop and manage workaround and get-well plans, and to widen the range of alternatives considered in those plans" (Pyles, 1984: 3). Dyna-METRIC is applied, then, in three primary areas: performance measures that assess the logistics system, problem parts identification, and spares requirements computations (Isaacson and others, 1988: 8).

Dyna-METRIC Assumptions. Dyna-METRIC makes multiple assumptions regarding the real world environment. Assumptions of Dyna-METRIC are included in Table 2.15.

TABLE 2.15

DYNA-METRIC ASSUMPTIONS (Pohlen, 1996)

1. Demands for spare parts are driven by flying hours or sortie rate.
2. Demands arrive randomly, with a known mean and variance according to either a Poisson or negative binomial distribution.
3. Demands and service process (repair and transportation) times are independent.
4. Repair and transportation times have known probability distributions.
5. All aircraft deployed to a single base are identical.
6. Pipeline segments are additive.
7. Aircraft performance measures are computed after attrition.
8. Cannibalization is always 100 percent successful and can be "done instantly and without consuming resources" (Isaacson and others, 1988: 95).
9. Repair times vary by component and transportation times vary by base.
10. Version 4.6 models unconstrained repair capability.
11. Version 6.4 models constrained repair capability.
12. Version 4.6 models a full cannibalization policy where all LRUs are cannibalized and "holes" are instantly consolidated on as few aircraft as possible.
13. Version 6.4 models maintenance policies of no cannibalization, full cannibalization or partial cannibalization when determining aircraft availability rates for a particular unit.
14. Ability to cannibalize a given LRU is all or nothing.

For more than a decade, the Air Force has used Dyna-METRIC to assess wartime stocks. As the accepted Air Force capability assessment model,

> Dyna-METRIC relates planned or current logistics support to wartime operational capability, considers wartime dynamics, reflects constrained repair and priority management, detects and diagnoses component support problems, and suggests cost-effective support packages to meet wartime requirements. (Pyles, 1984: 7)

Figure 2.6 is a pictorial representation of the logistics support network modeled by Dyna-METRIC.

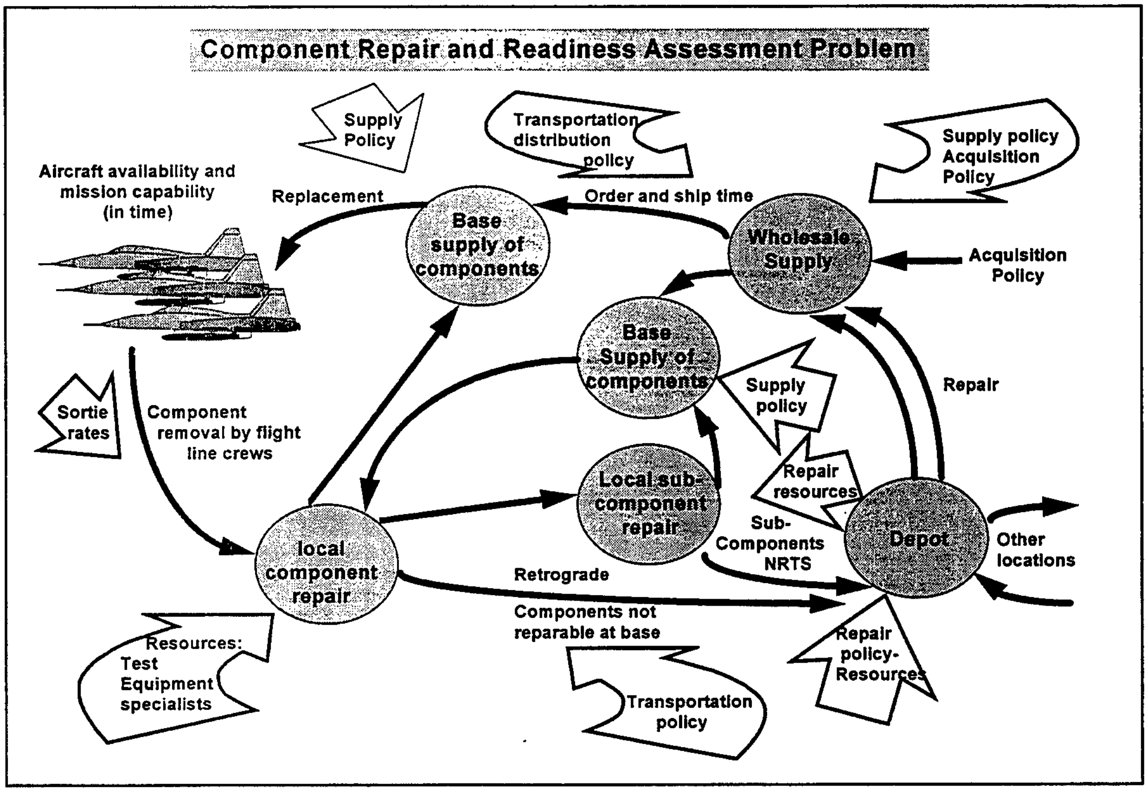

Figure 2.6 Aircraft Logistics Support Network (Isaacson and others, 1988: 6)

Currently, HQ AFMC uses Dyna-METRIC to evaluate a units' war-fighting capability based on the assessments provided by the model and to evaluate Readiness Spares Package (RSP) requirements (Niklas, 1996).

Dyna-METRIC Version 6.4

Dyna-METRIC version 6.4 "is a capability assessment model that relates logistics resources and pipelines to wartime readiness and sustainability" (Isaacson and Boren, 1993: v). Version 6.4 improves upon earlier model versions such as version 4.6 by more accurately representing the uncertainty which exists in both logistics and operations. In logistics, the model considers component demand variation, repair capacity constraints, and information lags and in operations, aircraft attrition, battle damage to stock, repair resources, and repair queues are considered (Isaacson and Boren, 1993: 2). In addition, the model allows the user to employ several management adaptations to cope with uncertainties. These management adaptations include lateral supply, lateral repair, priority repair, queue overflow, and exception reporting.

Version 6.4 is a simulation that incorporates Monte Carlo sampling rather than the analytic computations of probabilities used in version 4.6 to forecast how reparable support processes affect wartime readiness and capability as measured by aircraft availability (Isaacson and Boren, 1993: 4). Dyna-METRIC models aircraft availability as a direct function of the availability of the aircraft's components: LRUs and SRUs and views the logistics support system as having three echelons: the base, CIRF, and the depot. In addition, version 6.4 provides various measures of performance under three sets of cannibalization assumptions: full, designated (user specified), and none (Isaacson and Boren, 1993: 4). Finally, Dyna-METRIC represents three key logistics processes: supply, maintenance, and transportation. Table 2.16 describes the differences between Dyna-METRIC version 4.6 and version 6.4 capabilities.

TABLE 2.16

COMPARISON OF DYNA-METRIC VERSION 4.6 AND VERSION 6.4

(Isaacson And Boren, 1993: 3)

Capability	Version 4.6	Version 6.4
General		
Model Type	Analytic	Simulation
Requirements Determination	X	X
Pipeline Delays: Exponential	X	X
Fixed	X	
Designated Cannibalization	X	X
Options		
LRU Dependent Flying Programs	X	
Achievable Sorties	X	X
Lateral Supply		X
Locations		
Base and CIRF Overflow	Approx.	X
CIRF and Depot Allocation of Spares to Cutoff Bases	Always	X
CIRF and Depot Distribution: FCFS/Random	X	X
Priority		X
Scenario		
Aircraft Attrition	X	X
Base Damage to Stock and Repair		X
Base Deployment		X
Components		
Number of Indentures	3	2
Demands per: Flying Hour	X	X
Sortie	X	X
Condemnation	X	X
Quantity per Aircraft by Base	X	
Mission Essentiality	X	
Constrained Repair for SRUs		X
Maintenance Procedure: After Test	X	X
Before Test	X	X
Constrained Repair Scheduling		
Priority	Approx.	Approx.
Random	Approx.	X
Reports		
Performance Report	X	X
Pipeline Status	X	X
Problem Parts List	LRUs & SRUs	LRUs
Depot Workload Report	X	
Daily Demands Report	X	

Aircraft Sustainability Model (ASM)

In 1987, F. Michael Slay and Randall M. King of the Logistics Management Institute developed the ASM as a multi-indenture optimization model which enhances Dyna-METRIC by allowing the user to specify either of two objective functions: the probability of target availability where target availability is the number of spare parts available or an expected aircraft availability goal (Sherbrooke, 1992: 184). In addition, it improved the Dyna-METRIC LRU/SRU tradeoff logic. The ASM is based on a peacetime readiness model, the Aircraft Availability Model (Slay and King, 1987: 1-2). The ASM is an extension of the AAM that evaluates wartime sustainability by relating resources to fighting ability over a period of time (Slay and King, 1987: iii). More specifically, it allows the user to compute the minimum cost and associated optimal spares mix for a pre-determined flying schedule over a specified period of time (Slay and King, 1987 1-2).

ASM incorporates marginal analysis techniques to determine the best mix of assets from a given pool to achieve a desired aircraft availability goal (Slay and King, 1987: 1-1). ASM is a "two-indenture, two-echelon requirements model for a single weapon system" (Slay and King, 1987: 2-2). It distinguishes between LRUs and SRUs installed directly on an aircraft. While LRUs cause aircraft to be unavailable for use, SRUs only delay LRU repair (Slay and King, 1987: 2-2). The ASM makes the tradeoffs implicit in this indenture distinction. In addition, "ASM uses component specific data such as item failure rates, resupply times, and depot repair time to compute the necessary

quantity of spares to both fill the pipeline and achieve desired flying goals" (Gaddis and Haase, 1995: 106).

The assumptions of the ASM model are similar to those of other METRIC-based models. The bases are assumed to be uniform with respect to demands, resupply times, and repair capabilities. All failures occur at first-echelon sites. At the depot, the part may be repaired or condemned. If condemned, a replenishment from an outside source of supply is requested. In addition, ASM incorporates the effects of cannibalization (as described within the Dyna-METRIC model discussion). Each part can be identified as either cannibalizable or not cannibalizable (Slay and King, 1987: 2-2). Other assumptions are included in Table 2.17:

TABLE 2.17

AIRCRAFT SUSTAINABILITY MODEL VERSION 3.0 ASSUMPTIONS

1. An aircraft is down (not available) upon failure of an LRU for which no spare is available.
2. Repair consists of replacing a failed SRU at either the base or the depot.
3. Both the base and the depot operate under an (S-1, S) inventory policy (Slay and King, 1987: 2-2).

According to Gaddis and Haase:

> The execution of the ASM program is very straight forward. Component data for each National Stock Number (NSN) is loaded into the program via ASM data files. Next, the programmer inputs the planned flying scenario and the desired aircraft availability goal to be achieved. Additionally, a parameter file must be loaded which identifies the composition of the multi-echelon environment (number of bases) to be modeled. The program logic primarily operates by marginal analysis to get the lowest cost mix of spares necessary to achieve the

> aircraft availability goal. Once the program has been run, output files or "shopping lists" identifying the optimal mix of spares are easily obtainable. (1995: 106)

The ASM is the most recent model used by the Air Force to compute wartime spares requirements. Since the late 1980's, the Requirements Execution Availability Logistics Module (REALM) of the Weapon System Management Information System (WSMIS) has used ASM for requirements computation. As part of this system, ASM is currently used to compute Mobility Readiness Spares Package (MRSP)/In-place Readiness Spares Package (IRSP) requirements computations and perform budget allocations. In addition, it is used to compute spares requirements for unit deployments (Klinger, 1994: 46).

Chapter Summary

This chapter provided a review of the literature necessary to understand the importance and relevance of this research. The review covered several definitions of the term logistics and discussed the events leading to the emergence of a Lean Logistics philosophy. This chapter discussed the need for a responsive transportation system that provides rapid, time-definite delivery, and retrograde movement of critical combat assets during wartime. In addition, the chapter provided a comprehensive review of the Air Mobility Express concept and how it meets the goals of the Lean Logistics philosophy. Finally, reparables, the reparable pipeline, and the performance analysis models were discussed. Chapter III will describe the methodology that will be used in this research, the various inputs, and how resulting output will be analyzed.

III. Methodology

Introduction

This chapter describes the methodology used to conduct the research for this thesis on the projected Air Mobility Express (AMX) capability. First, this chapter will describe the sampling population and variables of interest. This is followed by the research design used to manipulate the variables and the research questions which need to be answered for this study. The data generation section outlines which specific instruments will be used in the analysis and the verification and validation of those instruments. Next is a discussion of the additional data required as inputs for the data generation instruments. Finally, this chapter will summarize the statistical methods used to analyze the data.

Sampling Population

This research will analyze the effect of AMX cargo aircraft space limitations on the transportation of in-theater combat aircraft reparables. Specifically, it will evaluate four squadrons (BAS1, BAS2, BAS3, BAS4) with air-to-ground missions from differing major commands deployed during the sustainment portion of a war. A unit from each major Air Force command was chosen in order to provide the most representative picture of reparable parts failure for weapons systems in a contingency operation.

The type of weapon system studied in this research is limited to one type of mission design series (MDS), the F-16C. The MDS used in this research includes only air-to-ground aircraft. The air-to-ground role was chosen for its high potential for

damage sustainment in a war. This type of weapon system is representative of both heavy flying and battle damaged reparable parts failure. As such, this represents a worst case scenario for reparable failures.

For further simplification, specific units with independent mobility readiness spares packages (MRSP) were identified. Independent packages are those that deploy with individual units. Dependent packages are those which deploy as a secondary shipment to support an additional unit by combining with the initial MRSP. Analysis of a unit with a dependent package could complicate or distort the research.

The scope will also be narrowed to include only the top 25 critical items assigned to the aircraft MRSP. Studies conducted by HQ AFMC/XPS verify similar results between the top 25 LRUs and all MRSP LRUs when analyzed with Dyna-METRIC (Niklas, 1996). Additionally, the use of the top 25 critical assets is a valid depiction of AMX transportation objectives as AMX was intended to transport only high priority sustainment items.

Variables of Interest

The independent variables used to conduct this research will be flying hours and the time it takes to transport the parts from the dock to the depot. This will be referred to as retrograde shipment time (RST). The dependent variable to be analyzed will be the weight and space of the parts requiring shipment in theater. These variables were chosen due to their impact on mission performance during DESERT SHIELD/DESERT STORM.

RST will be manipulated to evaluate the effect of transportation delay times on the total weight and space required to ship reparables. This research will also account for the limited space available to ship theses parts under the current AMX Sizing plan. For this experiment, the time it takes to ship a serviceable asset from the CONUS to the theater is assumed to be at least 3 days. In other words, a part will always be available for immediate shipment to the base in theater and will not be subject to delays other than the RST scenarios. RSTs will be varied to model the different scenarios of:

1. Favorable conditions
2. Maximum on Ground (MOG) exceeded
3. Increased threat

The specific RST for each scenario is located in Table 3.1. The weight and cube of the specific retrograde assets generated by changing this variable will be compared to determine the impact of current AMX sizing plans on its capability to return all the critical assets to the depot.

TABLE 3.1

RST SCENARIOS

	Favorable Conditions	**MOG Exceeded**	**Increased Threat**
RST	3 Days	3.5 Days	4 Days

Flying hours will be manipulated to model two different operations tempo. This will be used to analyze the effect upon the reparable parts requiring shipment resulting

from different degrees of operations tempo. Retrograde assets requiring shipment will be generated with flying hours set at a high and a low level. The specific values of the flying hour programs are listed in Table 3.2. The failed reparables resulting from these changes will be compared to determine the impact on the current AMX sizing plan's capability to return all critical assets to the depot. It is important to note that while the models used are based on the premise that the number of failures correspond directly to flying intensity, research has not validated this assumption (Kephart and Roberts, 1995: 5-12).

TABLE 3.2

FLYING HOUR PROGRAM

	High	Low
Flying Hours	3.0 Hours per Sortie	1.5 Hours per Sortie

Backlogs may be generated due to AMX's inability to transport all retrograde assets accumulated during the first 20 days. If this occurs, this study will estimate how long it takes to eliminate any backlogs generated for each of the RST and flying hour variations.

Since cargo space limitations can be exceeded by either total weight or total cubic feet required, both must be taken into consideration. The dimensions of a stretch DC-8 were used to determine the minimum space and weight available. This narrow body aircraft was chosen as it is representative of the commercial type aircraft that will be used

to support AMX missions. All military services are required to use this aircraft for the transportation of critical assets. Therefore, for the purposes of this study, the Air Force will be allotted one fourth of the weight and space available. The minimum space and weight available is 1900 cubic feet and 22,000 pounds.

The variables shown in Table 3.3 (μ and ν) represent the mean weight or cubic feet of the retrograde assets requiring shipment generated when the RST and flying hours are manipulated.

TABLE 3.3

MEAN SPACE/WEIGHT VARIABLES

	Favorable Conditions (RST)	MOG Exceeded (RST)	Increased Threat (RST)
High Flying Hours	μ_0	μ_1	μ_2
Low Flying Hours	ν_0	ν_1	ν_2

Research Design and Rationale

This research is a quantitative study of the effects of differing operating conditions on retrograde parts cargo space requirements generated using AMX in a Lean Logistics environment. A quantitative study was chosen because the basic paradigms found within the method of gathering and analyzing the data lent themselves to a quantitative study. According to John W. Creswell (1994: 5), quantitative studies are those that contain the following:

1. The researcher is independent from that being researched.
2. Reality is objective and singular, apart from the researcher.

3. The study is value-free and unbiased.
4. The language is formal.
5. The research process is deductive in nature with generalizations leading to prediction, understanding, and explanation.

On the other hand, qualitative studies maintain the paradigms of:

1. The researcher interacts with that being researched.
2. Reality is subjective and multiple as seen by participants in the study.
3. The study is value-laden and biased.
4. The language is informal.
5. The research process is inductive with patterns and theories developed for understanding.

It was determined that this study would follow a quantitative path for the following reasons:

1. It was not feasible for the researchers to interact with the study. The nature of the study involved a wartime scenario which cannot be replicated for research purposes.
2. A subjective study would not conclusively determine whether the current AMX sizing plan is capable of handling the cargo generated in a war.
3. The basic guidelines for the AMX sizing plan and Lean Logistics are not subject to individual values, therefore the study must be value free.

4. The research process must be deductive in order to provide accuracy and credibility through validity and reliability.

The variables mentioned in the previous section will be manipulated to evaluate their effect on the AMX cargo space requirements in theater. Generalizations concerning AMX's capability to handle all military requirements during a conflict in a Lean Logistics environment will be drawn from the results.

As direct observation of the logistics operations in a wartime scenario is not feasible, mathematical expressions, analytic models, and a simulation program will be used for this study. Simulations use algorithms encoded in a computer program to model the relationships between the elements of a system. Analytic models use mathematical expressions to describe the relationships between elements of a system.

Six basic steps will be performed to accomplish the research:

1. Calculate the top 25 critical assets using Dyna-METRIC version 4.6.
2. Calculate the leaned MRSP inventory levels using the Aircraft Sustainability Model (ASM) version 3.0.
3. Generate retrograde parts list with various RSTs and flying hours assuming infinite transportation capacity using Dyna-METRIC version 6.4.
4. Calculate AMX space requirements for expected failed component transportation using Microsoft Excel version 5.0.
5. Determine the amount of time required to reduce backlogs at the dock in theater (if any are generated) using Microsoft Excel version 5.0.

The first step uses the analytic model Dyna-METRIC 4.6 to determine which assets within the current MRSPs are critical to maintaining acceptable mission performance levels. Step two will employ the ASM (also an analytical model) to determine the optimum "shopping list" for the MRSPs under a "leaned" logistics environment.

Analytic models were chosen for the first two steps for three reasons:

(1) To incorporate the dynamic environment found in a wartime scenario.

(2) To handle the amount of calculations necessary to determine these levels and assets.

(3) To provide an exact solution: a simulation requires multiple runs to determine an average.

Next, a simulation program will be used to model the flow of aircraft spares through a wartime reparable asset pipeline. The decision to use a simulation program instead of an analytical program was based on the need to produce an environment where outcomes are random. Analytic models do not fully account for the effects of uncertainty and the strategies that logistics managers might use to mitigate that of war uncertainty (Isaacson and Boren, 1993: 1). Examples of these uncertainties include the reliability of the aircraft, attrition, and the demand process for components. The simulation version of Dyna-METRIC models uncertainty in both logistics and operations using Monte Carlo sampling in lieu of analytic computations of probabilities found in Dyna-METRIC version 4.6.

The last two steps in the research process require a spreadsheet of mathematical expressions to incorporate AMX capacity constraints and determine their effect on the shipment of retrograde assets. This method was selected because the models discussed previously do not explicitly account for transportation limitations. Mathematical expressions will provide an adequate assessment of the amount of space required to transport the retrograde assets after day 20. Additionally, the time it takes to eliminate any backlogs generated will be determined.

Research Objectives. There are three primary objectives to this research:

1. To determine the capability of the current AMX sizing plan to support the tactical portion of a contingency operation.
2. To determine the capability of the current AMX sizing plan to handle expected backlogs at the port due to variations in RST.
3. To determine the capability of the current AMX sizing plan to handle expected backlogs at the port due to variations in demand.

Investigative Questions. The models outlined above will be used to evaluate the transportation portion of the lean logistics philosophy by answering the following questions:

1. What is the current AMX sizing plan cargo capacity for Air Force reparable assets?
2. What are the transportation delay times associated with different environmental situations associated with conflicts?

Data Generation Methodology

Dyna-METRIC version 4.6 will be used to determine the 25 most critical assets for the F-16C MRSP. This version of Dyna-METRIC is an analytical model that uses mathematical equations specifically designed to forecast how logistics support processes would affect flying units' capability in a dynamic wartime environment. Although this version can generate many types of information for the decision-making process, this study will use only one of its capabilities.

The top 25 components that prohibit achieving a given aircraft availability goal will be identified and termed "critical assets". As stated earlier, studies conducted by HQ AFMC/XPS verify similar results between the top 25 LRUs and all MRSP LRUs when analyzed with Dyna-METRIC models (Niklas, 1996). Additionally, the use of the top 25 critical assets is a valid depiction of AMX transportation objectives as AMX was intended to transport only high priority sustainment items.

Specifically, Dyna-METRIC version 4.6 will be used to determine which assets within the current MRSPs are critical to attaining prescribed aircraft availability rates in the form of Direct Support Objective (DSO) levels. In the requirements mode, Dyna-METRIC version 4.6 minimizes the cost to meet a prespecified probability of having fewer than some prespecified number of aircraft grounded (DSO level) over a 20 day period. A hypothetical wartime scenario will be used to represent a typical notional tasking. Dyna-METRIC version 4.6 will then determine which assets are necessary to maintain the prescribed DSO. The DSO level was obtained from HQ AFMC/LGIW

(Frabata, 1996). Dyna-METRIC version 4.6 generates a problem parts report which lists the LRUs with unacceptable high probabilities of incapacitating at least some specified percentage of the fleet. Refer to Appendix B for the input parameters, a sample input data file, and a sample output problem parts report.

Once the critical assets have been identified, the ASM will be used to set the "leaned" inventory levels for this study. According to Sidnie Gerard, HQ AFMC/LGIW, there are three methods currently under review to lean the MRSP inventory levels (1996):

1. Combine the MRSP's from all four bases into one kit under the premise that all bases are deploying to the same location.
2. Reduce the kits from a 30 day supply to a 20 day supply under the premise that transportation will begin earlier.
3. Reduce the DSO levels.

Option 2 was selected as the most feasible option under the Lean Logistics philosophy of reduced inventories and faster transportation times. Option 1, although representative of our research, may not always represent reality. Additionally, it does not seem feasible to drop the already low DSO levels, as option 3 suggests, as it may negatively impact the war effort. Therefore, for this study, inventory levels were reduced by determining which assets were determined to be critical to sustaining the current flying program for the first 20 days of war. Transportation will begin on day 21 of the war.

The ASM was chosen specifically because as an extension of Dyna-METRIC version 4.6, it accounts for the dynamics of a wartime scenario and is capable of

computing inventory levels, but is more user friendly than Dyna-METRIC version 4.6. Later versions of Dyna-METRIC are incapable of computing inventory levels. ASM will be used to generate a list of the reparable assets required for a 20 day MRSP, assuming a \$2.67 million budget (two thirds of the budget used for the original 30 day scenario). Refer to Appendix C for the ASM input parameter file, an input LRU record file, and a sample LRU shopping list output file.

The simulation model, Dyna-METRIC version 6.4, was chosen for the next phase of the data generation process as it was specifically designed to simulate and assess the USAF logistics pipeline. Specifically, Dyna-METRIC version 6.4 will be used to determine the number and type of failed reparables using the critical assets and the "leaned" inventory levels generated by Dyna-METRIC version 4.6 and ASM, respectively. Dyna-METRIC version 6.4 uses information about the planned usage of aircraft, the characteristics of the aircraft components, and the demand for logistics resources to accomplish the following (Isaacson and Boren, 1993: 1):

1. Assess the effects of wartime dynamics.
2. Project operational performance measures.
3. Identify potential problems.

A snapshot of the retrograde pipeline will be generated for day 20 through day 49 of the war. This output will identify which assets will require shipment back to the depot assuming an infinite source of transportation. Refer to Appendix D for the Dyna-

METRIC version 6.4 input parameters, a sample input data file, and a sample output pipeline report.

A Microsoft Excel version 5.0 spreadsheet model will be used to convert this output to the total daily space and weight required. Additionally, the Excel spreadsheet will be used to determine the transportation space limitations to determine the effect of the current AMX sizing plan's ability to transport failed reparables from the deployed location. This spreadsheet model will calculate the space required to transport failed components back to the depot on a daily basis. The required space will then be compared to the space available on a daily basis. Figure 3.1 provides an example of the potential build up of retrograde assets over a specified period of time. The assets sit at the dock until day 21 when transportation begins. If there is insufficient capacity on the aircraft, some assets will continue to sit on the dock until day 22. More assets are potentially added due to continued flying on day 21.

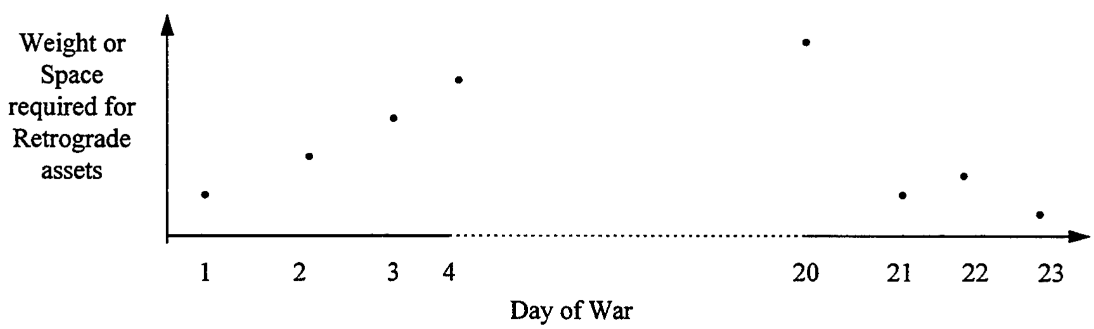

Figure 3.1 Retrograde Pipeline Flow

Any shortfalls in space available will be analyzed to determine how long it will take to eliminate any backlogs.

Verification. Verification is the process of determining whether the operational logic of the computer code follows the conceptual flow charted logic. Although no known formal verification of the Dyna-METRIC program code has been located, the incorporation of the model in the Air Force management information system is seen as authentication of the accuracy of its logic. Dyna-METRIC version 4.6 is an integral component of AFMC's Weapon System Management Information System (WSMIS) as an analytical computer model to assess planned and actual stock support to single aircraft mission design series (Isaacson, 1988: 1). Additionally, Dyna-METRIC version 4.6 is being used by the RAND corporation to conduct USAF directed research in areas such as Lean Logistics (Ramey and Pyles, 1992: 4). In light of the extensive use of Dyna-METRIC by both the Air Force and RAND, the program code is considered acceptable for this study.

Similarly, ASM is an enhancement of Dyna-METRIC version 4.6 and is currently being used in the Requirements Execution Availability Logistics Module (REALM) of the WSMIS to compute MRSP requirements. Due to it extensive use, the program is considered acceptable for use in this study. No evidence of the verification of Dyna-METRIC version 6.4 has been found. This must be considered when analyzing the results.

Validation. Validation is the process of determining if the computer simulation accurately portrays reality. The mathematical justification for Dyna-METRIC version 4.6

is the dynamic form of Palm's theorem proved by G.B. Crawford (Sherbrooke, 1992: 184).

Validation of Dyna-METRIC version 4.6 was further substantiated during the Coronet Warrior exercises in 1987 and 1988. At Coronet Warrior I, a thorough review of Dyna-METRIC modeling assumptions was accomplished in conjunction with other exercise planning. "The mechanics of Dyna-METRIC worked well and the modeling technique was proven conclusively by Coronet Warrior" (Rhodes, 1988: 80) Using lessons learned in Coronet Warrior I, Dyna-METRIC was updated and improved to provide a better mix of parts and reduce the excess capacity found in the readiness spares packages (Fulghum, 1988: 14). These improvements resulted in Dyna-METRIC predicting aircraft availability and sortie generation more accurately at Coronet Warrior II (Fulghum, 1988: 15).

No evidence of the validation of Dyna-METRIC version 6.4 has been found. As Dyna-METRIC version 6.4 replaces the analytic computations with Monte Carlo sampling techniques, the validation of Dyna-METRIC version 4.6 cannot be assumed to be maintained. The fact that no known documentation on the validation of Dyna-METRIC version 6.4 exists must be taken into consideration when analyzing the results. Validation of the Dyna-METRIC input parameters used for this study was accomplished through direct consultation with AFMC's Management Sciences Division (HQ AFMC/XPS).

Assumptions. Chapter II describes the assumptions of all the models used in this research. While these assumptions put certain limitations on the study, one is of primary concern. Both Dyna-METRIC models are based on the premise that failures correspond directly to flying intensity. Research has not validated this assumption. "Despite evaluating the data by three different statistical techniques, a conclusion is reached that significant correlation could not be obtained between demands/maintenance actions, flying hours, and number of sorties at the work unit code level" (Kephart and Roberts, 1995: 5-12). However, this research seeks to determine the effects of variation in demand. Since the Dyna-METRIC models assume demand is linearly related to flying hours, different flying hour profiles will be used to generate different demand patterns.

Data Collection

Dyna-METRIC models aircraft availability as a direct function of the availability of the aircraft components. Therefore, scenario, component, administrative, and location description data are required as inputs. In this research, the scenario data consists of aircraft records, the flying program, turn rate records, and attrition rates. Component data contains failure, repair, and resupply characteristics of LRUs and SRUs. Administrative data describes the Dyna-METRIC version 6.4 setup. Location descriptions are the depots, resupply parameters, and bases.

Direct observation to collect the aircraft component, scenario, and location data is infeasible due to the extensive amount of data required. Therefore, the data for the F-16C LRUs was obtained from the Dyna-METRIC Microcomputer Analysis System (DMAS)

located at HQ AFMC. A hypothetical flying program representative of a typical notional tasking will be used for portions of the scenario data.

Data Analysis

The data collected and generated will be used to determine if varying the RST has an effect on the current AMX sizing plan's capability to handle the cargo generated during the sustainment portion of a war. In addition, comparisons will be made between high and low flying hours to determine if there is an effect on the capability of AMX. Review Table 3.3 for the identification of variables. The six hypotheses used to test this data are as follows:

1. Test the mean weight and cube of retrograde assets generated under a high flying hour program to determine if either exceeds the available space. This hypothesis determines if the current AMX sizing plan is capable of supporting the tactical portion of a contingency operation under a high flying hour program under favorable conditions.

   Ho: $\mu_0 > 1900$ cubic feet or 22,000 pounds.

   Ha: $\mu_0 \leq 1900$ cubic feet or 22,000 pounds.

2. Test the mean weight and cube of retrograde assets generated under a low flying hour program to determine if either exceeds the available space. This hypothesis determines if the current AMX sizing plan is capable of supporting the tactical portion of a contingency operation under a low flying hour program and favorable conditions.

Ho: $\nu_0 > 1900$ cubic feet or 22,000 pounds.

Ha: $\nu_0 \leq 1900$ cubic feet or 22,000 pounds.

3. Test the mean weight and cube of retrograde assets generated under a high flying hour program to determine if exceeding MOG surpasses the available space. This hypothesis determines if the current AMX sizing plan is capable of supporting the tactical portion of a contingency operation under a high flying hour program and exceeded MOG conditions.

    Ho: $\mu_1 > 1900$ cubic feet or 22,000 pounds.

    Ha: $\mu_1 \leq 1900$ cubic feet or 22,000 pounds.

4. Test the mean weight and cube of retrograde assets generated under a low flying hour program to determine if exceeding MOG surpasses the available space. This hypothesis determines if the current AMX sizing plan is capable of supporting the tactical portion of a contingency operation under a low flying hour program and exceeded MOG conditions.

    Ho: $\nu_1 > 1900$ cubic feet or 22,000 pounds.

    Ha: $\nu_1 \leq 1900$ cubic feet or 22,000 pounds.

5. Test the mean weight and cube of retrograde assets generated under a high flying hour program to determine if an increased threat exceeds the available space. This hypothesis determines if the current AMX sizing plan is capable of supporting the tactical portion of a contingency operation under a high flying hour program and increased threat.

Ho: $\mu_2 > 1900$ cubic feet or 22,000 pounds.

Ha: $\mu_2 \leq 1900$ cubic feet or 22,000 pounds.

6. Test the mean weight and cube of retrograde assets generated under a low flying hour program to determine if an increased threat exceeds the available space. This hypothesis determines if the current AMX sizing plan is capable of supporting the tactical portion of a contingency operation under a low flying hour program and increased threat.

   Ho: $\nu_2 > 1900$ cubic feet or 22,000 pounds.

   Ha: $\nu_2 \leq 1900$ cubic feet or 22,000 pounds.

Statistical Testing Procedure. All the hypotheses will be tested using the small-sample T-Test of the hypothesis about the mean. The T-test is a parametric procedure which determines if the mean differs from a set value. An Excel spreadsheet will be used to perform these tests.

T-Test. This test will be a one-tailed test about μ_0 which can be either 1900 cubic feet or 22,000 pounds. The test statistic used is (McClave and Benson, 1994: 362):

$$t = \frac{\bar{x} - \mu_0}{s/\sqrt{n}}$$

where $\bar{x}$ is the mean weight or cube generated by the model (μ and ν in this research), s is the standard deviation, and n is the number of trials. For this study 20 trials will be run through the Dyna-METRIC version 6.4 simulation. A pretest of the model showed little

variation in the output with n set to higher values. The rejection region is $t < -t_{\alpha}$. For this study, the level of significance (α) will be 0.05 generating a confidence level of 95%. t_{α} is based on (n-1) degrees of freedom. For this experiment with twenty trials, there are 19 degrees of freedom which makes t_{α} equal to 1.729. Therefore the rejection region is anything less than -1.729.

While the T-test is a powerful tool for making inferences about population means, certain assumptions must be met in order for it to be valid. According to McClave and Benson "a random sample must be selected from a population with a relative frequency distribution that is approximately normal" (1994: 362).

Randomness of each run will be ensured by Dyna-METRIC version 6.4 using the Monte Carlo sampling technique to randomize the component arrivals, repairs, and requisition fill decisions for all assets in the pipeline. In other words, the Monte Carlo sampling technique produces probabilistic outcomes at critical decision points (Isaacson and Boren, 1993: 3-4). Additionally, each number stream used for each replication of the experiment will be altered. Random number seeds are used in Dyna-METRIC version 6.4 "for the various number streams that control the generation of removals, repair times, transportation times, NRTS actions, etc." (Isaacson and Boren, 1993: 86). The random number seeds will be obtained from the CRC Standard Mathematical Tables (McClave and Benson, 1994: 1113-1115).

Normality will be tested for using the Wilk-Shapiro/Rankit Plot Test. The computer software package, STATISTIX version 4.1 will be used to generate the Wilk-

Shapiro statistic. The Wilk-Shapiro/Rankit plot procedure examines whether a variable conforms to a normal distribution. This method produces a plot of the rankits and an approximate Wilk-Shapiro normality statistic. If the sample conforms to a normal distribution, a plot of the rankits produces a straight line. A high value for the normality statistic (greater than 0.905) indicates a normal distribution for a 95% level of confidence in a twenty-trial study (Conover, 1980: 468).

Nonparametric Test. If the data generated does not display a normal frequency distribution, the nonparametric sign test for a population median M will be will be used to determine the significance of the results. It requires only that the sample is randomly selected from a continuous probability distribution. The following describes the parameters of the sign test (McClave and Benson, 1994: 923):

H_o: $M > M_0$

H_a: $M \leq M_0$

M_0 is the weight or cubic space available

Test statistic: S = Number of measurements greater than the median

Observed significance level: p-value = $P(x \geq S)$ where x has a binomial distribution with parameters n and $p = 0.5$.

Rejection region: p-value ≤ 0.05

Chapter Summary

This chapter outlined the research methodology used in this study. First it specified that 25 assets from the MRSPs of four squadrons will be the target population.

It identified the RST and flying hours as the variables of interest. This chapter then discussed the use of Dyna-METRIC version 4.6, ASM version 3.0, Dyna-METRIC version 6.4, and Microsoft Excel version 5.0 to generate the necessary data for analysis. Additionally, the verification and validation of these models were detailed. Finally, this chapter summarized the statistical T-test which will be used to test the significance of the results. Chapter IV will present the results and analysis of the data obtained by implementing this methodology.

IV. Results and Analysis

Introduction

The purpose of this chapter is to present and analyze the results of the data collected using the methodology described in Chapter III. The results are designed to answer the thesis research problem and the research objectives. Chapter I outlined the problem faced by the USAF as two-fold:

1. To determine if the current AMX sizing plan is sufficient to handle the space and weight requirements for retrograde reparables generated by Lean Logistics under various operating conditions.
2. To determine the length of time required to eliminate the cargo backlog (build-up of reparables) under current AMX sizing plans.

In addition, Chapter I outlined three research objectives:

1. To determine the capability of the current AMX sizing plan to support the tactical portion of a contingency operation.
2. To determine the capability of the current AMX sizing plan to handle expected backlogs at the port due to variations in retrograde shipment time (RST).
3. To determine the capability of the current AMX-sizing plan to handle expected backlogs at the port due to variations in flying hours.

The results of the Dyna-METRIC version 6.4 simulation runs for each of the six scenarios described in Chapter III will be analyzed to determine if the normality assumption of the Small Sample Test of Hypothesis (*t* statistic) is satisfied. Once the

normality assumption is verified, hypothesis tests will be conducted to determine whether the mean weight and cubic feet requirements of retrograde assets generated under high/low flying hour programs and due to variations in RST exceed the available AMX cargo space capacity.

Data Computation Summary

The weight and cubic feet requirements generated by the Dyna-METRIC version 6.4 simulation runs are provided in Appendix E. Results are provided for each of the six scenarios for 30 consecutive days during the sustainment portion of a wartime scenario. For each scenario and each day of the scenario, simulation runs were conducted for 20 individual trials in order to satisfy the normality assumption.

Verification of Assumptions

According to McClave and Benson, the basic assumption necessary for the use of the Small Sample Test of Hypothesis (*t* statistic) is that "the sample population is random and has a relative frequency distribution that is approximately normal" (1994: 362). A brief discussion of how each of these two assumptions were satisfied is presented below.

Random Samples. To ensure independence between each of the twenty simulation runs, unique random number seeds were used and altered for each simulation run for each of the six scenarios. These random number streams specify 20 integer random number seeds of four columns each (Isaacson and Boren, 1993: 86). These random number seeds were used by Dyna-METRIC version 6.4 "for the various number streams that control the generation of removals, repair times, transportation times, NRTS actions, etc." (Isaacson and Boren, 1993: 86). In addition, Dyna-METRIC version 6.4

uses the Monte Carlo sampling technique to randomize the component arrivals, repairs, and requisition fill decisions for all assets in the pipeline and produce probabilistic outcomes at critical decision points (Isaacson and Boren, 1993: 3-4).

The random number seeds selected for each of the twenty trials were taken from the Random Number Table (abridged from the CRC Standard Mathematical Tables), Table I, in Statistics for Business and Economics (McClave and Benson, 1994: 1113-1115). Random numbers were selected beginning with row 63, selecting all of the 80 required numbers horizontally across the table. This process was repeated for each of the 20 runs by beginning with a random number seed that began with the next odd numbered row. Table 4.1 presents the random number seeds utilized in this research.

TABLE 4.1

RANDOM NUMBER SEEDS

Run	Random Number Seeds
1	0906600903207959545292648454540955288815165535112579375975961629666 0924223812426
2	16153080022650441744819596564274240563020003367107775107062528725 341912145740742
3	215815780202050897281793737621470754208097403486266899543805333862 15975561278095
4	446576699999324512818446360563793129345468876254719391125650126827 35729134084979
5	912272119931935270228406705462352161448629891686074186714951916968 50655000138140
6	653900522472958286098140639147255494854242627452335720294617237720 78962750496131
7	371699485139117896320095916487655364907139782170950233074301002754 82801150870225
8	374493036206694546900405253115627579534878662111638165150245349715 29244651570331
9	309868122342416583532153230502323058648205174079015433958861748184 69426379864995
10	824868484699254676324321850076213616481651202881244187052689512758 35562188532906
11	603369878207408534581356459089264452978985205410011253512133146452 35414393746891
12	976566317589303162750710092063219421861147348202031853403862780955 01360329901221
13	796260648603574176680778576020799242565183325884288507672811227175 05858563668335
14	180391436761337061771214346609329897401464708005333539858408132614 79080836215656
15	795562906804142162681538712856662673835822478733738873209443825580 52509260882674
16	239822583540055670061229302753148272323535071997043754311601355038 51710991596306
17	590373330026695622476992776123508424383486654709597972593872281171 923342248878077
18	467648627363003930173120436692402023527557306555435320318098476258 86840323745430
19	865918148252667615821497290053895347603649199437169754804379463702 86723853401715
20	039313330957047742116344517363628253990805607912846883325570388184 69207442633278

Normality. The method chosen to evaluate the assumption of normality was the Wilk-Shapiro/Rankit Plot Test. The statistical software package STATISTIX version 4.1 was used to generate the results of the Wilk-Shapiro Rankit Plot Test. As cited by Conover in the book, Practical Nonparametric Statistics, a Wilk-Shapiro Test Statistic of 0.905 is sufficient to establish the approximate normality of the data results for a 95% level of confidence with 20 trials. Appendix E provides the results of the Wilk-Shapiro Test Statistics for total weight and cubic feet requirements for each day based on 20 trials for 30 consecutive days for each of the six scenarios. As demonstrated by the results provided in Appendix E, the assumption of normality for the data collected is satisfied.

Hypothesis Testing

This research used a small sample T-test of the hypothesis about the mean to determine the statistical significance of the results. Table 4.2 shows the variables and scenarios that were tested in this study. For each variable, the units of measurement are both in pounds and cubic feet. The average space and weight requirements for the retrograde assets generated by Dyna-METRIC version 6.4 for day 20 through day 49 of the war can be found in Appendix F. The average weight and space generated for each day are end of day totals. In other words, the total weight and space generated for day 20 is the total weight and space to be shipped on day 21. Each mean weight and space required for retrograde shipment was tested to determine if it was larger than the space available on the cargo aircraft.

TABLE 4.2

MEAN SPACE/WEIGHT VARIABLES

	Favorable Conditions (3 Days RST)	MOG Exceeded (3.5 Days RST)	Increased Threat (4 Days RST)
High Flying Hours (3.0 hrs)	μ_0	μ_1	μ_2
Low Flying Hours (1.5 hrs)	ν_0	ν_1	ν_2

Appendix F also shows the test statistics for days 20 through day 49 of the war. As stated in Chapter III, the rejection region is: if the test statistic is less than -1.729. The following section indicates the statistical significance of the weight and space required for each day for each scenario with respect to each hypothesis.

Summary of Hypothesis Testing. The above variables were tested according to the following hypotheses and generated the following results:

1. Test the mean weight and cube of retrograde assets generated under a high flying hour program to determine if either exceeds the available space. This hypothesis determines if the current AMX sizing plan is capable of supporting the tactical portion of a contingency operation under a high flying hour program and favorable RST conditions.

   Ho: $\mu_0 > 1900$ cubic feet or 22,000 pounds.

   Ha: $\mu_0 \leq 1900$ cubic feet or 22,000 pounds.

   All tests but one resulted in sufficient evidence to support the rejection of Ho (Refer to Appendix F). In other words, both the weight and space available with the current AMX sizing plan are capable of supporting the tactical portion of a contingency operation except for the first day of transportation availability. As transportation is

unavailable until day 21, cargo has been building up on the docks. By day 20, a mean of 268.06 cubic feet is in excess of the available space for the cargo to be transported on day 21. However, as Table 4.3 indicates, the backlog is eliminated with the shipment on day twenty-two.

TABLE 4.3

BACKLOG GENERATION FOR

HIGH FLYING HOUR/FAVORABLE CONDITION SCENARIO

Day of Asset Accumulation	Day of Asset Departure	AVG Weight (lbs)	AVG ft^3	Excess Weight Required	Excess Space Required
Day 20	Day 21	20,766.59	2,168.06	0.00	268.06
Day 21	Day 22	15,107.44	1,593.73	0.00	0.00
Day 22	Day 23	11,381.64	1,207.33	0.00	0.00
Day 23	Day 24	8,786.71	935.05	0.00	0.00

2. Test the mean weight and cube of retrograde assets generated under a low flying hour program to determine if either exceeds the available space. This hypothesis determines if the current AMX sizing plan is capable of supporting the tactical portion of a contingency operation under a low flying hour program and favorable RST conditions.

Ho: $v_0 > 1900$ cubic feet or 22,000 pounds.

Ha: $v_0 \leq 1900$ cubic feet or 22,000 pounds.

All tests resulted in sufficient evidence to support the rejection of Ho (Refer to Appendix F). Both the weight and space available with the current AMX sizing plan are capable of supporting the tactical portion of a contingency. Table 4.4 shows the lack of backlog generated under this scenario.

TABLE 4.4

BACKLOG GENERATION FOR

LOW FLYING HOUR/FAVORABLE CONDITION SCENARIO

Day of Asset Accumulation	Day of Asset Departure	AVG Weight (lbs)	AVG ft^3	Excess Weight Required	Excess Space Required
Day 20	Day 21	10,355.52	1,084.53	0.00	0.00
Day 21	Day 22	7,586.57	806.359	0.00	0.00
Day 22	Day 23	6,021.90	629.995	0.00	0.00
Day 23	Day 24	4,645.80	489.001	0.00	0.00

Test the mean weight and cube of retrograde assets generated under a high flying hour program to determine if exceeding MOG surpasses the available space. This hypothesis determines if the current AMX sizing plan is capable of supporting the tactical portion of a contingency operation under a high flying hour program and exceeded MOG conditions.

Ho: $\mu_1 > 1900$ cubic feet or 22,000 pounds.

Ha: $\mu_1 \leq 1900$ cubic feet or 22,000 pounds.

All tests but one resulted in sufficient evidence to support the rejection of Ho (Refer to Appendix F). In other words, both the weight and space available with the current AMX sizing plan are capable of supporting the tactical portion of a contingency operation under this scenario except for the first day of transportation availability. As transportation is unavailable until day 21, cargo has been building up on the docks. By day 20, a mean of 268.06 cubic feet is in excess of the available space for the cargo to be transported on day 21. In this scenario, as Table 4.5 indicates, the backlog is not eliminated until the shipment departs on day twenty-three.

TABLE 4.5

BACKLOG GENERATION FOR

HIGH FLYING HOUR/MOG EXCEEDED SCENARIO

Day of Asset Accumulation	Day of Asset Departure	AVG Weight (lbs)	AVG ft^3	Excess Weight Required	Excess Space Required
Day 20	Day 21	20,766.59	2,168.06	0.00	268.06
Day 21	Day 22	15,795.37	1,662.31	0.00	30.37
Day 22	Day 23	12,438.24	1,315.55	0.00	0.00
Day 23	Day 24	9,904.53	1,045.29	0.00	0.00

4. Test the mean weight and cube of retrograde assets generated under a low flying hour program to determine if exceeding MOG surpasses the available space. This hypothesis determines if the current AMX sizing plan is capable of supporting the

tactical portion of a contingency operation under a low flying hour program and exceeded MOG conditions.

Ho: $\nu_1 > 1900$ cubic feet or 22,000 pounds.

Ha: $\nu_1 \leq 1900$ cubic feet or 22,000 pounds.

All tests resulted in sufficient evidence to support the rejection of Ho (Refer to Appendix F). Both the weight and space available with the current AMX sizing plan are capable of supporting the tactical portion of a contingency with a low flying hour program and increased MOG conditions. Table 4.6 shows the lack of backlog generated under this scenario.

TABLE 4.6

BACKLOG GENERATION FOR

LOW FLYING HOUR/MOG EXCEEDED SCENARIO

Day of Asset Accumulation	Day of Asset Departure	AVG Weight (lbs)	AVG ft^3	Excess Weight Required	Excess Space Required
Day 20	Day 21	10,355.516	1,084.531	0.00	0.00
Day 21	Day 22	8,064.043	848.225	0.00	0.00
Day 22	Day 23	6,398.979	669.076	0.00	0.00
Day 23	Day 24	5,270.654	549.406	0.00	0.00

5. Test the mean weight and cube of retrograde assets generated under a high flying hour program to determine if an increased threat exceeds the available space. This hypothesis determines if the current AMX sizing plan is capable of supporting the

tactical portion of a contingency operation under a high flying hour program and increased threat.

Ho: $\mu_2 > 1900$ cubic feet or 22,000 pounds.

Ha: $\mu_2 \leq 1900$ cubic feet or 22,000 pounds.

All tests but one resulted in sufficient evidence to support the rejection of Ho (Refer to Appendix F). In other words, both the weight and space available with the current AMX sizing plan are capable of supporting the tactical portion of a contingency operation under this scenario except for the first day of transportation availability. As transportation is unavailable until day 21, cargo has been building up on the docks. By day 20, a mean of 268.06 cubic feet is in excess of the available space for the cargo to be transported on day 21. In this scenario, as Table 4.7 indicates, the backlog is not eliminated until the shipment departs on day twenty-three.

TABLE 4.7

BACKLOG GENERATION FOR

HIGH FLYING HOUR/INCREASED THREAT SCENARIO

Day of Asset Accumulation	Day of Asset Departure	AVG Weight (lbs)	AVG ft^3	Excess Weight Required	Excess Space Required
Day 20	Day 21	20,766.59	2,168.06	0.00	268.06
Day 21	Day 22	16,424.47	1,726.53	0.00	94.59
Day 22	Day 23	13,396.70	1,413.34	0.00	0.00
Day 23	Day 24	11,184.21	1,170.74	0.00	0.00

6. Test the mean weight and cube of retrograde assets generated under a low flying hour program to determine if an increased threat exceeds the available space. This hypothesis determines if the current AMX sizing plan is capable of supporting the tactical portion of a contingency operation under a low flying hour program and increased threat.

   Ho: $\nu_2 > 1900$ cubic feet or 22,000 pounds.

   Ha: $\nu_2 \leq 1900$ cubic feet or 22,000 pounds.

All tests resulted in sufficient evidence to support the rejection of Ho (Refer to Appendix F). Both the weight and space available with the current AMX sizing plan are capable of supporting the tactical portion of a contingency with a low flying hour program and increased threat conditions. Table 4.8 shows the lack of backlog generated under this scenario.

TABLE 4.8

BACKLOG GENERATION FOR

LOW FLYING HOUR/INCREASED THREAT SCENARIO

Day of Asset Accumulation	Day of Asset Departure	AVG Weight (lbs)	AVG ft^3	Excess Weight Required	Excess Space Required
Day 20	Day 21	10,355.516	1,084.531	0.00	0.00
Day 21	Day 22	8,298.226	877.256	0.00	0.00
Day 22	Day 23	7,056.694	736.921	0.00	0.00
Day 23	Day 24	5,790.870	607.563	0.00	0.00

Table 4.9 summarizes the results of the hypothesis testing. As it indicates, the cargo aircraft could handle both the weight and space requirements all but one day in three of the six scenarios. Day 20 is the final day when transportation is not available and retrograde assets have been piling up on the dock. However, as shown previously, these backlogs take at most two days to eliminate.

TABLE 4.9

SUMMARY OF DAYS INDICATING

INSUFFICIENT EVIDENCE TO REJECT Ho

Flying Hours/RST	Weight Requirement	Space Requirement
1.5/3.0	None	None
1.5/3.5	None	None
1.5/4.0	None	None
3.0/3.0	None	Day 20
3.0/3.5	None	Day 20
3.0/4.0	None	Day 20

Chapter Summary

This chapter presented the results and analysis of the data collected using the methodology described in Chapter III. It discussed the results obtained in order to answer the two-fold problem faced by the USAF and the thesis research objectives. The assumptions of the Small Sample Test of Hypothesis (*t* statistic) were discussed and verified. The statistical techniques used to analyze the output generated by Dyna-

METRIC version 6.4 were reviewed and the results were provided in narrative form. Finally, a summary of the hypothesis testing was provided. Chapter V will provide conclusions and suggestions for further research.

V. Conclusions and Recommendations

Introduction

The purpose of this chapter is to discuss the conclusions drawn from the research required to analyze Air Mobility Express (AMX) requirements operating within a Lean Logistics wartime sustainment environment. The chapter begins by providing a general review of the thesis research followed by a summary of the research findings, conclusions, and management interpretations drawn from the output of the Dyna-METRIC version 6.4 simulation trials. The chapter concludes with a list of recommendations for further research.

Research Summary

This research was conducted to determine the capability of current AMX sizing plans to handle the shipment of retrograde assets during the sustainment portion of war operations. The current AMX sizing plan calls for one aircraft (military or commercial narrow body) to ship critical retrograde assets to and from the theater of operations daily with the capability to surge to two aircraft. This analysis was conducted by examining the effects of varying Retrograde Shipment Time (RST) and flying hours on the space and weight of retrograde assets generated daily for day 20 through day 49 of the war. These were then compared to the space and weight available on a typical cargo aircraft.

Several assumptions were made in order to establish feasible parameters for this study. The following is a list of the assumptions used to perform this research:

1. The inherent model assumptions of Dyna-METRIC version 4.6, the Aircraft Sustainability Model version 3.0, and Dyna-METRIC version 6.4 as cited in Chapter II were relevant.
2. Only four identical F-16C squadrons deployed to the same location were evaluated. Each F-16C squadron maintained 18 aircraft each.
3. Only the top 25 critical assets for each Mobility Readiness Spares Package (MRSP) as identified by Dyna-METRIC version 4.6 were evaluated for AMX transportation requirements. All other cargo is assumed to be transported by opportune airlift or other methods.
4. Replacement assets are assumed to be available for immediate shipment from the CONUS to the theater upon requisition.
5. Reparable failure rates are based on flying hours and are strictly correlated to flying hours.

While these assumptions put certain limitations on the study, assumption five is of primary concern. Both Dyna-METRIC models are based on the premise that failures correspond directly to flying intensity; however, prior research has not validated this assumption. In a recent study conducted by Kephart and Roberts, they concluded that "despite evaluating the data by three different statistical techniques, a conclusion is reached that significant correlation could not be obtained between demands/maintenance actions, flying hours, and the number of sorties at the work unit code level" (1995: 5-12). However, since the flying hour variable was analyzed as high versus low demand and

Dyna-METRIC assumes a linear relationship between flying hours and demand, this disparity will not impact this study.

This research used the F-16C weapon system because its air-to-ground wartime role represents the worst case scenario, generating parts failures due to both high flying hour programs and combat damage. Four identical squadrons of 18 aircraft were deployed with a 20 day MRSP to a single overseas location. The traditional 30 day MRSP was reduced to a 20 day MRSP to account for the reduction in the mobility footprint resulting from Lean Logistics initiatives and the fact that AMX transportation resources would be available on day 21 of the war. These MRSPs contained assets which were determined to be the top 25 assets critical to maintaining acceptable mission performance levels.

The methodology employed in this research involved the application of:

1. Dyna-METRIC version 4.6 to determine the top 25 critical assets.
2. The Aircraft Sustainability Model version 3.0 to calculate the leaned MRSP inventory levels.
3. Dyna-METRIC version 6.4 to generate the retrograde parts list with various RSTs and flying hours, assuming infinite transportation capacity.
4. Microsoft Excel version 5.0 to calculate AMX space and weight requirements for expected failed components returning to the depot and to determine the amount of time required to reduce any cargo backlogs experienced in theater.

The Dyna-METRIC and ASM models were specifically chosen for this research because they were designed to represent the USAF logistics pipeline performance in a dynamic

wartime environment. The basic design of the research contained two factors: flying hours and RST. Flying hours were varied from low to high and RST was varied to account for ideal conditions, Maximum on Ground (MOG) exceeded, and increased threat. This 2x3 design produced six treatments to compare against the maximum space and weight available on a typical cargo aircraft.

The data generated from this research was evaluated using a small sample t-test of hypothesis. The data collected satisfied the assumptions of randomness and normality necessary to perform this test. The t-test was used to determine if the weight and space required for retrograde assets generated each day exceeded the weight and space available on the cargo aircraft each day. The t-test allowed conclusions to be drawn on the capability of the current AMX sizing plan's capability to perform its mission under the given scenarios.

Summary of Findings

This research was conducted to address three research objectives. The first objective was to determine the impact of using only one AMX aircraft per day to transport reparable assets in a wartime sustainment scenario. By analyzing the space required for retrograde parts and the amount of time required to eliminate any backlogs, conclusions may be drawn on the capability of the current AMX plans to accomplish its wartime tasking under Lean Logistics. The hypothesis testing conducted in Chapter IV demonstrated the impact of the daily weight and space required to ship retrograde assets back to the depot for day 21 through day 49. The test showed that the weight and space required to ship retrograde assets exceeded that available in only three of the six scenarios

for a short period of time. The high flying hour scenarios all generated a backlog of assets on day 20 of the war using one AMX aircraft (Refer to Appendix F). For all other scenarios, the AMX sizing plan was sufficient to handle the assets generated during the first 30 days of a contingency operation in a Lean Logistics environment.

The second objective was to determine the impact of variations in the retrograde shipment time (RST) on expected cargo backlogs at the outbound port, using AMX to transport reparables back to the depot. Evaluation of this aspect of Lean Logistics is essential to determining the overall impact of Lean Logistics in conjunction with AMX plans on mission accomplishment when normal operations are influenced by exceeded MOG and increased threat. The hypothesis testing conducted in Chapter IV demonstrated the impact of the daily weight and space required to ship retrograde assets back to the depot for day 21 through day 49 with various retrograde shipment times. The test showed that the weight and space required to ship retrograde assets did not exceed that available when the RST was increased for the different scenarios (Refer to Appendix F).

The final research objective was to determine the effect that variations in flying hours has on expected backlogs at the port. By analyzing variable flying hours, conclusions can be drawn on the capability of one AMX aircraft to handle the retrograde carcasses from the base to the depot with an increased operations tempo. The hypothesis testing conducted in Chapter IV demonstrated the impact of the daily weight and space required to ship retrograde assets back to the depot for day 21 through day 49. The test showed that the weight and space required to ship retrograde assets exceeded that

available for a short period of time in the three scenarios which had increased flying hours. The high flying hour scenarios all generated a backlog of assets on day 20 of the war using one AMX aircraft (Refer to Appendix F).

Conclusions Drawn From Research

By meeting the above research objectives, the perceived problems faced by the Air Force can be addressed. Recall from Chapter I, the research problems are:

1. To determine if the current AMX sizing plan is sufficient to handle the space and weight requirements for retrograde reparables generated by Lean Logistics under various operating conditions.
2. To determine the length of time required to eliminate the cargo backlog (build-up of reparables) under current AMX sizing plans.

The conclusion drawn from this research is that the current AMX sizing plan is sufficient to handle the space and weight requirements for retrograde reparables generated within the following parameters:

1. Four squadrons consisting of 18 F-16C aircraft each are deployed.
2. All 72 aircraft are deployed to the same location.
3. All aircraft are operating within the established high and low flying hour programs.
4. RSTs are within those set for MOG exceeded and increased threat conditions.
5. There is 100% availability of assets upon requisition.
6. The 20 day MRSP assets are allocated as listed in the 25 critical item list (Refer to Table C.3).

The current AMX sizing plan is sufficient to handle the cargo backlog generated for the 30 day period evaluated for each of the low flying hour scenarios and after day 22 for the high flying hour scenarios. Although the weight and space required to ship retrograde assets exceeded that available on day 20 for all of the high flying hour scenarios, the research showed it took only two days to eliminate the backlog generated. In addition, the current sizing plan stipulates that the carrier must be capable of surging to two AMX aircraft when required. Operating under this premise, all potential backlogs within these scenarios would be eliminated.

Although the current AMX sizing plan is capable of handling the retrograde assets generated in these scenarios, it must be noted that this study considers only retrograde assets generated by 72 F-16C aircraft. In a wartime environment, over 3,000 aircraft of varying types will be engaged in the war effort (Niklas, 1996). Therefore, while the space available in the current AMX sizing plan is sufficient to support four F-16 squadrons, it may not be capable of supporting the entire war effort.

Management Implications

This study is relevant for the following reasons:

1. This study shows the impact of the AMX sizing plan on cargo backlogs to determine if current plans are sufficient to keep reparables flowing through the pipeline.
2. This study indicates how long it takes to eliminate any cargo backlogs generated.

The positive indication of the success of AMX operating within a Lean Logistics wartime environment should indicate to decision makers that the current AMX sizing plan is sufficient only within extremely narrow parameters. The realization that this study evaluates only 2.4% of the aircraft involved in a contingency operation indicates that the current AMX sizing plan may need to be increased to ensure reparables are kept flowing through the pipeline. While the backlogs generated in these scenarios were minimal, there is a great potential for larger backlogs to build up as more weapon systems are added to the war effort.

The ramifications of an insufficient AMX sizing plan are widespread. When operating within a Lean Logistics environment, it is imperative that sufficient express transportation is planned and available to keep reduced inventories of reparables flowing through the pipeline. Insufficient transportation which causes large cargo backlogs in theater will most certainly result in longer pipeline times, reduced reparable availability, and subsequently, reduced mission performance by combat aircraft in theater.

In addition to increased pipeline times, the build up of assets awaiting transportation out of the theater can require substantial management attention during a period of already heightened perplexity. Intransit visibility of reparable parts, aircraft space allocations, and transportation priorities become critical to theater commanders. AMX was developed to transport all of the Services' critical assets on a priority system. As such, aircraft space allocations are determined to a certain extent by theater commanders and their representatives at the outbound port. Ensuring that the AMX sizing plan is sufficient prior to a conflict is an easier problem to resolve than

incorporating work-arounds and establishing aircraft space allocations and transportation priorities during wartime. Instead, theater commanders can devote all of their attention to the war effort if logistical support systems are soundly developed during peacetime.

Recommendations for Further Research

During the course of this research, numerous possibilities for suitable future research were identified. As extensions of this research, the following suggestions merit further investigation:

LRUs. The number of LRUs used as inputs into the Dyna-METRIC version 6.4 model simulation could be expanded to include all NSNs authorized in the F-16C MRSP The current research showed significant results for the top 25 critical item LRUs used as inputs for this study. Using the full authorization of parts in the F-16C MRSP and incorporating the availability of opportune airlift to transport other than high priority sustainment cargo would provide more indicative results under the same conditions as this study. Operating under this premise, opportune airlift could also be used to eliminate any high priority reparable backlogs generated by using only one AMX aircraft. This type of study would show how well routine shipments work in concert with AMX missions to eliminate any cargo backlogs.

Weapon Systems. The type of weapon system deployed could be expanded to include other aircraft such as cargo, tanker, and bomber aircraft. The current research showed significant results for four F-16C flying squadrons used as the basis for this study. Using the LRU data for several weapon systems deployed to a remote location would provide a diverse sample of spare part failures generated by aircraft performing

separate missions. The analysis should be conducted under the same conditions as this study. The results of such a study could provide significantly different results than those presented by this research. This type of study could analyze the impact of having an increase in total aircraft in theater which would generate more reparables to be shipped out of the theater. Research tasking only four squadrons of F-16 C aircraft indicated that the space provided by one AMX aircraft was adequate but limited. A study which incorporated more aircraft might indicate that the current AMX sizing plan is insufficient to handle the reparables generated.

Depot Repair. The depot repair times could be manipulated to represent "leaned" depot repair times. The depot repair times used in this study were current depot repair times provided by the DMAS data base. The depot repair times remained constant throughout each scenario. By using "leaned" depot repair times or those experienced under the two-level maintenance concept, the speed of asset availability from the depot would increase (HQ USAF/LGM-2, 1995: 19). Having assets available in a shorter time period in effect reduces the pipeline. This decreased pipeline time analysis would provide insight into the ramifications of asset availability on aircraft availability in theater.

Simulation Model. A simulation model could be developed (or Dyna-METRIC version 6.4 could be modified) to incorporate the feature of constrained transportation to the Lean Logistics system represented by this research. Different constraints on transportation could be analyzed to determine the overall affect on the availability of spare parts at the deployed location and ultimately the affect on aircraft availability.

The simulation model used in this research, Dyna-METRIC version 6.4, assumes infinite transportation availability. In effect, any actual transportation delay is assumed to be absorbed by the depot repair time. Unfortunately, this limitation of the Dyna-METRIC model eliminates the capability to analyze the overall effect of assets being delayed on aircraft availability in theater. With the incorporation of Lean Logistics initiatives and the emphasis on fast, reliable transportation, this aspect must be considered to ensure AMX planning is sufficient to sustain combat capability. Constrained transportation is a truer representation of the "real world" situation and should be tested to determine the affect on both the logistics system as well as aircraft availability in theater.

Chapter Summary

This chapter discussed the conclusions drawn from the research required to analyze Air Mobility Express requirements operating within a Lean Logistics wartime sustainment environment. A general review of the thesis research was provided followed by a summary of the research findings and management interpretations drawn from the output of the Dyna-METRIC version 6.4 simulation trials. The chapter concluded with a list of recommendations for further research.

Thesis Summary

Lean Logistics was developed in response to budget cuts, force reductions, and a new political world order. In general the objective is to minimize the total system wide costs of the Air Force organization. At the root of Lean Logistics is the trade-off between inventory and transportation. The Air Force is currently seeking to cut cost by reducing

inventories and employing faster transportation where possible. This thesis addressed the issue of reducing the inventories maintained in the MRSPs and increasing the speed of the transportation of reparables in the sustainment portion of a war. More specifically, the objective of this thesis was to determine if the current sizing plan for the rapid transportation employed by the Air Force, AMX, was capable of supporting the retrograde assets generated during the sustainment portion of the war.

In order to determine the capability of the current AMX sizing plan, a comprehensive literature review was first accomplished to provide the background on Lean Logistics, AMX, and the reparable pipeline process. Upon completion of this review, computer modeling programs (Dyna-METRIC version 4.6, Dyna-METRIC version 6.4, and the Aircraft Sustainability Model version 3.0) were employed to analyze the effect of varying such parameters as flying hours and retrograde shipment time on the weight and space required to move retrograde assets.

An analysis of the results indicated that the current sizing plan was capable of handling the retrograde cargo generated by four F-16C squadrons in all of the scenarios evaluated. However, the scenarios evaluated were under extremely tight and limited parameters. A conjecture can be made from this research that while the current plan is capable of supporting four F-16C squadrons, it may not be sufficient to support the entire war effort. An insufficient AMX sizing plan can lead to increased cargo backlogs in theater which could result in serious mission degradation, not only for the Air Force, but the other services as well.

Logistics is an integral part of the war effort which must be established during peacetime to minimize the chaos of contingency operations. By strictly analyzing the cargo space required to ship critical assets prior to a conflict, direct combat operations can be emphasized during the conflict. This research recommends that the current AMX sizing plan should be increased in order to accommodate the projected reparable asset cargo loads generated during a conflict.

Appendix A: F16-C Research Data

TABLE A.1

F16-C RESEARCH DATA

NSN	Nomenclature	QPA	Cost	Weight	Cubic Feet
1270012383662	TRANSMITTER	1	$258,447	235	17.760
1270013093077	COMPUTER	1	$125,368	28.5	4.422
1290013223711	INTERFACE	1	$176,194	109	9.343
1650011657203	CYLINDER	4	$43,632	92	6.003
1650012289276	DRIVE, CONS	1	$44,178	135	7.999
1660013452115	REGULATOR	1	$7,549	18	2.007
1660013632742	TURBINE, AI	1	$14,424	25	3.146
1680011689396	ADAPTER, RE	2	$4,427	4.5	.481
2835011156111	SHAFT, TURBINE	1	$4,349	7.5	.520
2840013114795	SEAL AIR	12	$999	4	.925
4320000620511	PUMP, AXIAL	2	$8,723	25	3.255
4810010549843	VALVE, REGU	1	$7,637	8	1.814
4810010996392	VALVE, SOLENO	1	$8,728	5.5	.910
5826010124864	ASYMMETRY	1	$4,040	8	.124
5895011126380	RECEIVER-T	1	$33,116	25	3.159
5985011469283	ANTENNA	1	$8,901	8	1.467
5985012122950	ANTENNA	1	$127,757	195	20.989
6115012465622	GENERATOR	1	$16,122	33	3.255
6130012099062	POWER SUPPLY	2	$8,227	8.5	1.858
6340011538696	CONTROL, AL	1	$3,880	3	.486
6610011150131	ALTIMETER	1	$13,117	4.33	.311
6620012788027	INDICATOR	1	$4,788	6	.609
6625011938861	INDICATOR	4	$27,700	29	3.385
5865013249103	PROCESSOR	1	$55,939	32	1.756
6605012562380	NAVIGATION	1	$140,732	130	19.374

(DMAS and DO28 data file provided by HQ AFMC/LGIW and HQ AFMC/XPSA)

Appendix B: Dyna-METRIC Version 4.6 Problem Parts Determination

TABLE B.1

DYNA-METRIC VERSION 4.6 PROBLEM PARTS DETERMINATION

DATA RESULTS

National Stock Number (NSN)	Demand Rate Per Flying Hour	Repair Cycle Time (Days)	Percent Base Repair (PBR)	Condemnation Rate
1270012383662	.00162	3.0	0.0	0.0
1270013093077	.00346	1.0	0.0	0.0
1290013223711	.00226	6.0	.37	0.0
1650011657203	.00037	6.0	0.0	0.0
1650012289276	.00050	6.0	0.0	0.0
1660013452115	.00049	5.0	0.0	0.0
1660013632742	.00058	2.0	0.0	0.0
1680011689396	.00064	4.0	0.0	0.0
2835011156111	.00239	5.0	.02	0.0
2840013114795	.00106	1.0	0.0	0.0
4320000620511	.00090	6.0	0.0	0.0
4810010549843	.00027	2.0	.12	0.0
4810010996392	.00050	4.0	1.0	0.0
5826010124864	.00028	5.0	0.0	0.0
5895011126380	.00268	6.0	0.0	0.0
5985011469283	.00090	6.0	0.0	0.0
5985012122950	.00186	6.0	.45	0.0
6115012465622	.00162	3.0	0.0	0.0
6130012099062	.00052	4.0	0.0	0.0
6340011538696	.00026	5.0	0.0	0.0
6610011150131	.00093	4.0	.07	0.0
6620012788027	.00042	6.0	0.0	0.0
6625011938861	.00099	1.0	0.0	0.0
5865013249103	.00652	6.0	0.0	0.0
6605012562380	.00541	4.0	0.0	0.0

(DMAS data file provided by HQ AFMC/LGIW)

DYNA-METRIC VERSION 4.6 INPUT PARAMETERS

PROBLEM PARTS DETERMINATION

Notes:

(1) The options used for this research are highlighted in bold print and explained in Tables B.2 through B.16.

(2) Only the Dyna-METRIC Version 4.6 header records and columns used in this research are addressed in this appendix. Further information can be obtained by referencing Dyna-METRIC Version 4, Modeling Worldwide Logistics Support of Aircraft Components (Isaacson and others, 1988: 140-202).

(3) Header records and column definitions are direct quotations from the Dyna-METRIC Version 4 Handbook (Isaacson and others, 1988: 140-202).

(4) The actual input parameter records and data files for this experiment are included at the end of this appendix as well as an example of a portion of the problem parts output report.

ADMINISTRATIVE DATA

Header Record: NONE

Definition: Provides general information about the input data, including a heading, labels for each mission, times of analysis, and a switch for setting exponential or deterministic distributions for repair/transportation times. Also given are administrative delay times for each echelon (base, CIRF, and depot). Table B.2 and B.3 will summarize the data inputs for the second and third record of this input file. The first record is simply a heading for the entire input data file.

TABLE B.2

INPUT RECORD: ADMINISTRATIVE DATA (SECOND RECORD)

Column	Description
1	Cutoff Direction Switch 0 = Cutoff parameters in the BASE and TRNS record groups apply to forward transportation only. 1 = Cutoff parameters in the BASE and TRNS record groups apply to both forward and retrograde transportation. **For this research, a value of "1" is input.**
2	Exponential Repair Switch 0 = Transportation and repair delays have a deterministic distribution. 1 = Transportation and repair delays have an exponential distribution. **For this research, a value of "0" is input.**
3-7	Base Administrative Time The deterministic delay (in days) experienced by LRUs removed at the flight line prior to entering base level repair. **For this research, a value of "1" is input.**
13-17	Depot Administrative Time The deterministic delay (in days) experienced by LRUs and SRUs that have been NRTSed to the depot from bases and CIRFs, after arrival at the depot and prior to entering depot level repair. **For this research, a value of "5" is input.**
20-30	Data Set Version Must contain "Version 4.6" to correctly identify the input data set. **For this research, "Version 4.6" is input.**

TABLE B.3

INPUT RECORD: ADMINISTRATIVE DATA (THIRD RECORD)

Column	Description
1-4	Times of Analysis These are the days for which output reports are requested. **For this research, a value of "30" is input.**

OPTION SELECTION

Header Record: OPT

Definition: Defines the options that generate Dyna-METRIC's reports and specifies the parameters that further define the options.

TABLE B.4

INPUT RECORD: OPTION SELECTION

Column	Description
5-7	Option Number (requests output reports). **For this research, the following options are used:** **8 -- Problem LRUs List:** **Reports those LRUs that individually have a high confidence of grounding more than a target number of aircraft (the target and confidence level are specified in option 11)** **11 -- Performance Report:** **Produces an output called *data.out* showing each base's performance for each day of analysis under two assumptions: full and partial cannibalization. Performance measures include expected available aircraft, number of sorties, the probability of achieving a specified level of aircraft, the number of FMC aircraft at a minimum requested confidence level, and the probability of having less than the target level of aircraft degraded due to component support.**
 8-10 11-15	Parameters First Parameter Second Parameter **OPT 8 - Only the first parameter, the maximum number of LRUs to be reported, is used. For this research a value of "40" is input.** **OPT 11 - The first parameter is the percent of aircraft that may be degraded (0-100). The second parameter is the confidence level (between 0 and 1).-- For this research a value of "25%" and ".95" are input, respectively.**

DEPOT DESCRIPTION

Header Record: DEPT

Definition: Provides characteristics about each depot, including the availability of resupply and when unconstrained repair of LRUs and SRUs starts.

TABLE B.5

INPUT RECORD: DEPOT DESCRIPTION

Column	Description
1-4	Depot Name. The name of the depot. May not be a header (such as "DEPT") or the name of another location (base, CIRF, or depot). **For this research, one depot is used and named "DEPO".**
35-39	Resupply Start. Day resupply of parts ordered from an outside supplier becomes available. **For this research, a value of "31" is input.**
40	Resupply Availability Switch. 0 = Parts ordered in peacetime do not continue to arrive at the depot prior to the resupply start time. 1 = Parts ordered in peacetime continue to arrive at the depot prior to the resupply start time. **For this research, a value of "0" is input.**
51-55	RR Repair Start. This is the day the depot can start repairing LRUs coded RR. **For this research, a value of "1" is input.**
56-60	RRR Repair Start This is the day the depot can start repairing LRUs coded RRR. **For this research, a value of "1" is input.**
61-65	SRU Repair Start This is the day the depot can start repairing SRUs and subSRUs. **For this research, a value of "1" is input.**
66	SRU Cannibalization Switch. 0 = Depot does not cannibalize SRUs and subSRUs. 1 = Depot cannibalizes SRUs and subSRUs. **For this research, a value of "1" is input.**

BASE DESCRIPTION

Header Record: BASE

Definition: Provides characteristics about each base, including its link to a CIRF (if any), resupply availability, and when unconstrained repair of LRUs and SRUs starts. A record is required for each base. The number of bases may not exceed DMBASES.

TABLE B.6

INPUT RECORD: BASE DESCRIPTION

Column	Description
1-4	Base Name. The name of the base. May not be a header (such as "BASE") or the name of another location **For this research there are four (4) bases. The names of the bases are as follows: "BAS1", "BAS2", "BAS3", and "BAS4".**
35-39	Resupply Start. Day resupply of parts ordered from a supplier other than the CIRF or depot first becomes available. **For this research, a value of "31" is input for each of the four bases.**
40	Resupply Availability Switch 0 = Parts ordered in peacetime from a supplier other than the CIRF or depot do not continue to arrive at the base prior to the resupply start time. 1 = Parts ordered in peacetime from a supplier other than the CIRF or depot continue to arrive at the base prior to the resupply start time. **For this research, a value of "0" is input.**
51-55	RR Repair Start This is the day the base can start repairing LRUs coded RR. **For this research, a value of "31" is input.**
56-60	RRR Repair Start This is the day the base can start repairing LRUs coded RRR. **For this research, a value of "3" is input.**
61-65	SRU Repair Start This is the day the base can start repairing SRUs and subSRUs. **For this research, a value of "31" is input.**

66	<u>SRU Cannibalization Switch</u> 0 = The base does not cannibalize SRUs and subSRUs. 1 = The base cannibalizes SRUs and subSRUs. **For this research, a value of "1" is input.**
67-71	<u>Sustained Demand Start Time.</u> The day that components begin to break according to their sustained demand rates (entered in the VTM record group) as opposed to their wartime demand rates. If set to 0 the wartime rates remain in effect for the entire wartime scenario. **For this research, a value of "0" is input.**
80	<u>Onshore Switch</u> 0 = Indicates an offshore base. 1 = Indicates an onshore base. **For this research, a value of "1" is input.**

DEPOT TRANSPORTATION

Header Record: TRNS

Definition: Describes the transportation resource connecting bases and CIRFs with depots. If a record is not entered for some location directly connected to a depot, transportation between the two is assumed to be instantaneous and never cut off.

TABLE B.7

INPUT RECORD: DEPOT TRANSPORTATION

Column	Description
1-4	Base Name. **For this research, the base names indicated in Table B.6 are input.**
6-9	Depot Name. **For this research all bases use the services of a single depot (DEPO).**
11-15	Transportation Time to Depot. Number of days required to ship an unserviceable part from the base location to the depot. **For this research, transportation times to the depot will be held constant. A value of "9" isinput.**
17-21	Transportation Time from Depot. Number of days required to ship a serviceable part from the depot to the base location. **For this research, transportation times from the depot will be held constant. A value of "9" is input.**
23	Transportation Availability Switch. 0 = Parts ordered from the depot in peacetime do not continue to arrive at the base/CIRF prior to the transportation start time. 1 = Parts ordered from the depot in peacetime continue to arrive at the base/CIRF prior to the transportation start time. **For this research, a value of "0" is input.**
25-29	Transportation Start. The day that transportation from the depot first becomes available. **For this research , a value of "31" is input.**

AIRCRAFT LEVELS

Header Record: ACFT

Definition: Specifies the number of aircraft assigned to each base during peacetime and on each day of war. A base with no ACFT record is assigned no aircraft.

TABLE B.8

INPUT RECORD: AIRCRAFT LEVELS

Column	Description
1-4	Base Name. The name of the base for which aircraft levels are specified. Must be named in the BASE record group. Enter at most one record per base. **For this research, each of the four bases identified in Table B.6 are used.**
5-8	First Aircraft Level. Number of aircraft at the base. **For this research, each of the four bases are assigned "18" aircraft.**

SORTIE RATES

Header Record: SRTS

Definition: Specifies the average daily number of sorties required per aircraft at each base during peacetime and on each day of war. Aircraft at bases with no associated SRTS record do not fly sorties.

TABLE B.9

INPUT RECORD: SORTIE RATES

Column	Description
1-4	Base Name. The name of the base for which sortie requirements are specified. Must be named in the BASE record group. Enter at most one record per base. **For this research, a record is established for each base: BAS1, BAS2, BAS3, and BAS4.**
5-8	First Sortie Rate. The number of daily sorties per aircraft, which may not exceed the turn rate on the base's TURN record. Rates may change DMCHANGE times during the scenario. Not all rates must be used. The last rate specified carries throughout the rest of the scenario. **For this research, a value of "2.6" is input for the first sortie rate.**
9-12	Day Second Rate Starts. **For this research, the second sortie rate starts on day 6.**
13-16	Second Sortie Rate. **For this research, a value of "2.1" is input for the second sortie rate.**
17-20	Day Third Rate Starts. **For this research, the third sortie rate starts on day 11.**
21-24	Third Sortie Rate. **For this research, a value of "1.2" is input for the third sortie rate.**
25-28	Day Fourth Rate Starts. **For this research, the fourth sortie rate starts on day 14.**
29-32	Fourth Sortie Rate. **For this research, a value of "1.1" is input for the fourth sortie rate.**

FLYING HOURS PER SORTIE

Header Record: FLHR

Definition: Specifies the number of flying hours required per sortie at each base during peacetime and for each day of the war. Aircraft at bases with no FLHR record fly sorties of one hour each.

TABLE B.10

INPUT RECORD: DATA FLYING HOURS PER SORTIE

Column	Description
1-4	Base Name. The name of the base for which flying hours per sortie are specified. Must be named in the BASE record group. Enter at most one record per base. **For this research, a record is established for each base: BAS1, BAS2, BAS3, and BAS4.**
5-8	First Flying Hour Level. The number of flying hours per sortie per day. Flying hour levels may change as many as DMCHANGE times during the scenario. Not all levels must be used; the last level specified carries throughout the rest of the scenario. **For this research, a value of "3" is input. All four bases are given identical flying hour times.**

MAXIMUM SORTIE RATES

Header Record: TURN

Definition: Specifies the maximum number of sorties a mission capable aircraft can fly per day at each base during peacetime and on each day of war. Aircraft at bases with no TURN records do not fly sorties.

TABLE B.11

INPUT RECORD: MAXIMUM SORTIE RATES

Column	Description
1-4	Base Name. The name of the base for which the maximum sortie rates are specified. Must be named in the BASE record group. Enter at most one record per base. **For this research, a record is established for each base: BAS1, BAS2, BAS3, and BAS4..**
5-8	First Maximum Sortie Rate. The maximum number of daily sorties per mission capable aircraft. Should be larger than the sortie rates on the SRTS record. Rates may change as many as DMCHANGE times during the scenario. Not all "turn rates" must be used; the last rate specified remains throughout the scenario. **For this research, a value of "3.2" is input for the first maximum sortie rate.**
9-12	Day Second Rate Starts **For this research, the second maximum sortie rate starts on day 11.**
13-16	Second Maximum Sortie Rate **For this research, a value of "2.6" is input for the second maximum sortie rate.**

LRU DESCRIPTION

Header Record: LRU

Definition: Describes the failure, repair, and resupply characteristics of each LRU. A pair of these records is required for each LRU. The number of LRUs may not exceed DMLRUS.

TABLE B.12

INPUT RECORD: LRU DESCRIPTION (FIRST RECORD)

Column	Description
1-16	LRU Name. Unique LRU identifier, such as NSN. May not be the name of another part and may not begin with a header word (such as "LRU"). **For this research, LRUs are identified by their NSNs.**
18-21	Depot Name. The name of the depot that repairs the LRU. Leave blank if the LRU is not repaired by a depot. **For this research, the depot is referenced by "DEPO".**
23	Level of Repair. 1 = LRU can be repaired at a base, CIRF, or depot. 2 = LRU can only be repaired at a CIRF or depot. 3 = LRU can only be repaired at a depot. **For this research, a value of "1" is input.**
25	CIRF Reparability Switch. Allows the CIRF to be a special facility that repairs only a subset of LRUs in analyses where both base and depot have repair capabilities. 0 = CIRF cannot repair the LRU. 1 = CIRF can repair the LRU (if level of repair is not 3). **For this research, a value of "0" is input.**
26-28	Quantity per Aircraft (QPA). Number installed per aircraft. **For this research, actual QPA values provided by the DMAS data file are input for all NSNs. Refer to Table A.1.**

29-31	Minimum quantity. Minimum quantity of the LRU required for the aircraft to be mission capable (i.e., the QPA less the number that may be broken without impairing the aircraft's capability). **For this research, the minimum quantity is always equal to the value in column 26-28 of this record.**
32	Demands per Sortie Indicator. 0 = Demand rates are per flying hour. 1 = Demand rates are per sortie. **For this research, a value of "0" is input.**
33	NRTS/Condemnation/Failed SRU Policy. Determines when the decision is made to NRTS or condemn the LRU and when its failed SRUs are detected. 0 = Wait until after attempting repair to make decision (in effect, delay the decision one repair time + time awaiting maintenance). 1 = Before attempting repair, make decision. **For this research, a value of "1" is input.**
34-40	Onshore Demand Rate. At onshore bases, this is the expected demands per sortie or flying hour. **For this research, actual values provided by the DMAS data files are input. Refer to the demand rates per flying hours in Table B.1.**
41-47	Offshore Demand Rate. At offshore bases, this is the expected demands per sortie or flying hour. **For this research, actual values provided by the DMAS data file are input. Refer to the demand rates per flying hours in Table B.1.**
48-52	Lone Base Repair Time (in days). The repair time at bases not served by a CIRF. **For this research, actual values provided by the DMAS data file are input. Refer to the base repair times in Table B.1.**
48-52	Lone Base NRTS Rate. Proportion of LRUs arriving for repair at bases not served by a CIRF that are sent to a higher echelon for repair. **For this research, actual values provided by the DMAS data file are input. Refer to the Percent Base Repair in Table B.1.**

59-62	Lone Base Condemnation Rate Fraction of removals at bases not served by a CIRF that are declared condemned. **For this research, actual values provided by the DMAS data file are input. Refer to the Base Condemnation Rates in Table B.1.**

TABLE B.13

INPUT RECORD: LRU DESCRIPTION (SECOND RECORD)

Column	Description
1-16	LRU Name. Must match LRU name given on the first record of the pair. **See column 1-16 of the first record of LRU description.**
32-36	Depot Repair Time. Number of days required to repair the LRU at the depot. **For this research, actual values provided by the DMAS data file are input.**
38-41	Depot Repair Limit. The maximum number of the LRU that can be repaired at the depot each day during wartime. 0 = No repair limit. 1 = No depot repair. **For this research, a value of "0" is input.**
43-46	Depot Condemnation Rate. Fraction of removals at the depot that are declared condemned. **For this research, actual values provided by the DMAS data file are input.**
47-51	Peacetime Resupply Time (in days). The expected time for the highest echelon repairing the LRU to procure a replacement during peacetime. **For this research, actual values provided by the DMAS data file are input.**

52-56	Wartime Resupply Time (in days) The expected time for the highest echelon repairing the LRU to procure a replacement during wartime. **For this research, actual values provided by the DMAS data file are input.**
58-65	Cost Unit cost of the LRU. **For this research, actual values provided by the DMAS data file are input. Refer to the LRU cost figures in Table A.1.**
67-73	Work Unit Code **For this research, actual values provided by the DMAS data file are input**
75	No Cannibalization Indicator. 0 = LRU can be cannibalized. 1 = LRU cannot be cannibalized. **For this research, a value of "0" is input.**

APPLICATION FRACTIONS

Header Record: APPL

Definition: Specifies the fraction of each base's aircraft that contain a given LRU. Bases for which application fractions are not specified default to application fractions of one (all aircraft at the base contain the LRU).

TABLE B.14

INPUT RECORD: APPLICATION FRACTIONS

Column	Description
1-16	LRU Name. The name of the LRU for which application fraction data are specified. Must be named in the LRU record group. Enter as many records as needed per LRU. **For this research, LRUs are identified by their NSNs.**
18-21	First Base Name Name of the first base to which the first application fraction applies. **For this research, the base names indicated in Table B.6 are input.**
22-26	First Application Fraction. Fraction of the aircraft stationed at the first base that contain the LRU. **For this research, a value of "1" is input.**

VARIANCE-TO-MEAN

Header Record: VTM

Definition: Specifies an LRU's maintenance type and gives its wartime demand rate multipliers, pipeline variance-to-mean ratio, and the probability that a partially mission capable repair resource is able to repair it. LRUs for which VTM records are not given are assumed to be maintenance type 0 (RR), essential for all missions, reparable on a partially mission capable repair resource, to have wartime demand rates equal to peacetime demand rates, and to have pipelines with Poisson distributions.

TABLE B.15

INPUT RECORD: VARIANCE-TO-MEAN DATA

Column	Description
1-16	LRU Name. The name of the LRU for which variance-to-mean data are specified. Must be named in the LRU record group. Enter at most one record per LRU. **For this research, LRUs are identified by their NSNs.**
18	Maintenance Type. 0 = Assigns the LRU to maintenance type RR. 1 = Assigns the LRU to maintenance type RRR. **For this research, actual values provided by the DMAS data files are input. All LRUs are assigned a value of "1".**
20-23	Onshore Demand Rate Multiplier. A number multiplied by the peacetime onshore demand rate (in the LRU record group) to obtain the wartime onshore demand rate. **For this research, actual values provided by the DMAS data files are input. All LRUs are assigned a value of "1".**
25-28	Offshore Demand Rate Multiplier. A number multiplied by the peacetime offshore demand rate (in the LRU record group) to obtain the wartime offshore demand rate. **For this research, actual values provided by the DMAS data files are input. All LRUs are assigned a value of "1".**

30-33	Variance-to-Mean Ratio. The variance-to-mean ratio of the LRU's pipelines. <1 = Pipelines have a Binomial Distribution. 1 = Pipelines have a Poisson Distribution. >1 = Pipelines have a Negative Binomial Distribution. **For this research, actual values provided by the DMAS data files are input. All LRUs are assigned a value of "1".**
35-38	Partial Reparability. Fraction of the time that a partially mission capable repair resource is able to repair the LRU. It must be a number between 0 and 1. This field is disregarded if the LRU is not assigned to a repair resource. **For this research, actual values provided by the DMAS data files are input. All LRUs are assigned a value of "1".**

STOCK LEVELS

Header Record: STK

Definition: Specifies each part's stock level at each location (depots, CIRFs, and bases). A stock level for a location reflects the number of serviceables and unserviceables on-hand and in transit to the location, less the number due out (or committed) to a forward location; it is not simply the number on the shelf. If all stock levels for a component were summed across all locations, the resulting number would be the number of assets in the entire system less those installed on aircraft.

TABLE B.16

INPUT RECORD: STOCK LEVELS

Column	Description
1-16	Part Name. Name of the LRU, SRU, or subSRU to which the stock levels apply. Must be named in the LRU, SRU, or subSRU record group. Enter as many records as needed per part. **For this research, parts are identified by their NSNs.**
17	Replacement Switch. Switch indicating whether the stock level replaces (0), is added to (1) or is subtracted from (2) the stock level previously given for all locations on this record. **For this research, a value of "0" is input.**
18-21	First Stock Location. Name of the location to which first stock level applies. **For this research, the base names indicated in Table B.6 are input.**
22-26	First Stock Level Stock assigned to the first location. **For this research, actual MRSP authorized stock levels provided by the DMAS data file are input.**
77-80	Day Levels Start. Day on which the stock levels on this record go into effect. Each day must be greater than or equal to the previous day on any prior stock record. **For this research, a value of "1" is input.**

SAMPLE DYNA-METRIC 4.6 INPUT FILE FOR PROBLEM PARTS DETERMINATION

```
EC28 F016C Data Set for Problem Parts Determination
Davila-Martinez/Bollinger
10  1.0     5.0   VERSION 4.6
  30
OPT
      8 40
     11 25 .95
DEPT
DEPO                               31.  0          1.   1.   1.  1
BASE
BASX                               31.  0         31.   3.  31.  1 0.         1
TRNS
BASX DEPO  9.    9.   0 31.
ACFT
BASX 18
SRTS
BASX 2.6   6 2.1  11 1.2  14 1.1
FLHR
BASX 3.0
TURN
BASX 3.2 11  2.6
LRU
  F0110100       DEPO   1 100100100000043500004350180O 0012 000000000 0100 0000
  F0110100       0000 0000 000008250 9999 00000019000170 02954807 23100   0
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1005000566753    1000 0000 000008900 9999 00000303003030 00012632 75AAB   0
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1005010446174    0700 0000 000004300 9999 00070073000730 00026968 75ABC   0
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1660005678852    1000 0100 000001500 9999 00000525005250 00003639 47AAA   0
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2835013083769     DEPO   1 1001001000000050000005000100 0085 000000100 0100 0000
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2840013571941     DEPO   1 1012012000000036000003600500 0100 000000500 0100 0000
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4810011530975	DEPO	00001	0000
1260012511150	DEPO	00002	0000
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1270992255327	DEPO	00002	0000
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1005000566753	75AAB	GUN,AUTOMANOP01002
1005010418667	75ADA	DRIVE ASSENOP01002
1005010446174	75ABC	AMMUNITIONNOP01002
1005010463536	75ACA	UNIT,TRANSNOP01002
1005010502735	75ABA	AMMUNITIONNOP01002
1005010502736	75ABB	AMMUNITIONNOP01002
1005010556484	75ACE	ACCESS UNINOP01002
1260012511150	74KB0	GENERATOR,AAA01001
1270012330011	74AN0	RECEIVER-TAAA01002
1270012383662	74AP0	TRANDEITTEAAA01002
1270013093077	74CE0	COMPUTER,FAAA01001
1270013333608	74BT0	SIGHT,HEADAAA01001
1270013998233	74AQ0	PROCESSOR,ADJ01001
1270992255327	74BM0	GENERATOR,AAA01001
1290013223711	75DJ0	INTERFACE AAA01001
1560011026385	24BA0	TANK,FUEL,NOP01002
1560011358956	14CBB	LEADINGEDGAAA01002
1560011950672	12CAC	CANOPY,MOVNOP01001
1560012898930	11GDR	STABILIZERAAA01001
1620010540042	13FAB	VALVE,HYDRNOP01002
1620011365173	13FAC	NOSE BX ASNOP01002
1620012521051	13BAC	SHOCK STRUNOP01001
1620012521115	13BAA	AXLE,LANDINOP01001
1620012521116	13BAB	AXLE,LANDINOP01001
1620013471770	13CAA	SHOCK ABSONOP01001
1630010848399	13EAA	VALVE ASSENOP01002
1630011184492	13EAD	CONTROL BONOP01002
1630012173141	13EAG	SENSOR,WHENOP01002
1630012173142	13EAF	CONTROL BONOP01002
1630012523593	13DAA	WHEEL,LANDNOP01001
1630013201448	13DBA	WHEEL,LANDNOP01002
1630013826774	13EAH	BRAKE,MULTNOP01001
1650010394983	45AG0	ACCUMULATOAAA01002
1650010394984	45AH0	ACCUMULATOAAA01002
1650010568914	24AD0	PUMP,HYDRANOP01002
1650010586259	46AFA	MOTOR,HYDRAAA01002
1650011061594	14BA0	CYLINDER AAAA01002
1650011297553	13CBB	CYLINDER ANOP01001
1650011657203	14BB0	CYLINDER AAAA01002
1650012289276	42AA0	DRIVE,CONSAAJ01002
1650012785720	13BCD	CYLINDER ANOP01001
1650013004351	13BCD	CYLINDER ANOP01001
1660005678852	47AAA	CONVERTER,AAA01002
1660011408406	41ACB	SENSOR,CONAAA01002
1660011965999	41ADB	CONTROLLERAAA01002
1660013199517	41AAP	CONTROL BOAAA01001
1660013417291	47AD0	REGULATOR,NOP01004
1660013452115	41AAA	REGULATOR,AAA01002
1660013632742	41ABN	TURBINE,AIAAA01002
1680010841544	13AAC	CONTROL ASNOP01002
1680011484167	12CCA	ACTUATOR,ENOP01002
1680011689396	14DH0	ASYMMETRY AAA01001
1680012585608	24CB0	CONTROLLERNOP01002
1680012632357	74DD0	PANEL ASSEAAA01001
1680012649871	14DP0	GEARBOX ASNOP01001
1680012952653	271BN	ADAPTER,THAAA01001

2835010738989	24AB0	GAS GENERANOP01002
2835011156111	24EBA	SHAFT,TURBAAA01002
2835012080169	24EA0	GEARBOX,ACNOP01002
2835013083769	24DA0	ENGINE,GASNOP01002
2840011906884	27ECD	SEAL,METALAAA01001
2840011921067	27ECL	FLAP,PRIMAAAA01001
2840013114795	27ECG	SEAL AIR,AAAA01001
2840013126039	27ECN	FLAP,AUGMEAAA01001
2840013571941	27ECP	FLAP,AUGMEAAA01001
2910011355681	24DBA	FUEL CONTRNOP01002
2915011472644	46AFA	PROPORTIONAAA01002
2915011911818	27GAX	SENSOR,TEMAAA01001
2915011920847	27GAA	PUMP,FUEL,AAA01001
2915012000119	27GDH	FUEL CONTRAAA01001
2915012355188	46AB0	CARTRIDGE AAA01002
2915013097889	27GAH	PUMP,FUEL,AAA01001
2915013548333	27GDC	PUMP,FUEL,AAA01001
2915013585052	27GAL	FUEL CONTRAAA01001
2925011150306	24DC0	CONTROLLERNOP01002
2925011909213	27DD	EXCITER,IGAAA01001
2925011949737	27GPH	ROTOR,GENEAAA01001
2925012597092	27GPL	CONTROL AFAAA01001
2925012949823	27GPJ	STATOR,ENGAAA01001
2935012377995	46AP0	COOLER,LUBAAA01002
2995011904934	27GHC	ACTUATOR,VAAA01001
2995011922637	27EDC	ACTUATOR,HAAA01001
2995012669692	27BFA	ACTUATOR,IAAA01001
2995013130343	27GTA	VALVE ASSEAAA01001
4320000620511	45AAA	PUMP,AXIALAAA01002
4320013088876	27GJH	PUMP,ROTARAAA01001
4320013783398	27GMC	PUMP,ROTARAAA01004
4810010549843	46CB0	VALVE,REGUAAA01002
4810010996392	24BD0	VALVE,SOLENOP01002
4810011237254	46CA0	VALVE,PREDAAA01002
4810011307379	24BE0	VALVE,REGUNOP01002
4810011530975	41AAB	VALVE,REGUAAA01002
4810012257171	231CA	VALVE,REGUAAA01002
4810012590464	24DDJ	VALVE,SOLENOP01002
4810013169850	46CP0	VALVE,SOLEAAA01002
4810013451092	41AAC	VALVE,REGUAAA01002
4810013490405	46AN0	VALVE,BUTTAAA01002
5810010269624	63CBB	INTERFACE AAA01002
5810010508115	63CBA	SPEECH EQUAAA01002
5810012737820	65AD0	TRANSPONDEAAA01002
5821010621019	62CD0	RECEIVER-TAAA01002
5821012287057	63BL0	RECEIVER-TAAA01004
5826010121938	71AA0	RECEIVER-TAAA01002
5826010124864	71AB0	ADAPTER,REAAA01002
5826010409798	71BA0	RECEIVER,RAAA01002
5826013608302	71DA0	RECEIVER,RAAA01003
5831005358123	64AC0	INTERCOMMUNOP01002
5841013499175	74LA0	RECEIVER-TAAA01004
5865010450982	76DD0	DISPENSINGNOP01004
5865010481589	76CA0	CONTROL,INAAA01002
5865010535396	76EH0	IMPEDANCE AAA01001
5865010805675	76EK0	RECEIVER,CAAA01001
5865011106043	76ED0	RECEIVER,CAAA01001
5865013249103	76EG0	PROCESSOR,AAA01003

5895006232912	64AA0	AMPLIFIER AAA01002
5895010211647	76DB0	DISPENSER,NOP01004
5895010423265	76EA0	CONTROL-INAAA01002
5895010491178	76EB0	CONTROL,INAAA01003
5895011074586	76EC0	INDICATOR,AAA01003
5895011126380	65AA0	RECEIVER-TAAA01002
5895011405901	69AC0	PANEL ASSEAAA01002
5895011435443	74JA0	DATA DISPLAAA01002
5895011549125	76EL0	AMPLIFIER-AAA01001
5895012301284	74LE0	CONVERTER,AAA01004
5895012422033	74JL0	DATA ENTRYAAA01001
5895012489012	74HB0	DATA TRANSNOP01001
5895013080933	76BC0	BLANKER,INAAA01001
5895013102157	76EE0	CONTROL,REAAA01002
5915010558592	76DE0	FILTER,RADNOP01004
5930011839085	76DC0	SWITCH ASSNOP01004
5945011709363	75DP0	INTERFACE AAA01002
5985011469283	76EW0	ANTENNA AAA01002
5985012122950	74AM0	ANTENNA AAA01002
5985012949788	71DD0	ANTENNA COAAA01004
5998013227746	75DT0	ELECTRONICNOP01002
5999010803978	75DD0	ELECTRONICAAA01002
6110011640394	75EL0	PANEL,POWENOP01002
6110011640395	75EM0	PANEL,POWENOP01002
6110011656844	42BD0	CONTROL,GEAAA01002
6110013916067	42BF0	CONTROL,GEAAA01002
6115012368434	42AE0	GENERATOR,AAA01002
6115012465622	42AJ0	GENERATOR,AAA01002
6130011408200	42AK0	CONVERTER,AAA01002
6130011498915	44AC0	POWER SUPPAAA01002
6130012072734	74JB0	POWER SUPPAAA01002
6130012099062	42AN0	POWER SUPPAAA01002
6130012486604	75CAA	POWER SUPPNOP01002
6130013311438	75CAA	POWER SUPPNOP01002
6130013861430	42GD0	CHARGER,BAAAA01004
6340011538696	64AD0	CONTROL,ALAAA01002
6340013102536	271FC	DETECTOR,IAAA01001
6605010784943	74BE0	UNIT,RATE AAA01002
6605011190832	51BA0	INDICATOR,AAA01002
6605012562380	74DF0	NAVIGATIONAAA01004
6610002008773	51DA0	INDICATOR,AAA01002
6610010397817	14AF0	ACCELEROMEAAA01002
6610010404430	51AC0	INDICATOR,AAA01002
6610010521945	51EA0	COUPLER,MOAAA01002
6610010929846	51BB0	INDICATOR,AAA01002
6610011150131	51AB0	ALTIMETER,AAA01002
6610011192298	51AA0	INDICATOR,AAA01002
6610012438003	51AD0	INDICATOR,AAA01002
6610012531448	14FK0	TRANSMITTEAAA01001
6610012531449	14FK0	TRANSMITTEAAA01001
6610013081859	51FA0	COMPUTER,AAAA01004
6615007076478	51BC0	GYROSCOPE,AAA01002
6615010427834	14AG0	RATE GYROAAAA01002
6615011297445	14AE0	PANEL ASSEAAA01002
6615011496398	14FC0	SENSOR,PNEAAA01002
6615013619746	14AP0	COMPUTER,FAAA01003
6620011670874	46EC0	TRANSMITTEAAA01002
6620011805183	271AB	INDICATOR,AAA01002

6620012199413	241AA	INDICATOR,AAA01001
6620012788027	46ED0	INDICATOR,AAA01002
6620013107401	27GPU	COMPUTER,EAAA01001
6620013226193	27GPT	PROCESSOR,AAA01001
6625011938861	74KA0	INDICATOR,AAA01002
6680009763923	47ABC	INDICATOR,AAA01002
6680010604248	46EJ0	INDICATOR,AAA01002
6680010749369	46EG0	TRANSMITTEAAA01002
6680012615242	46EZA	CONTROLUNIAAA01002
6685012482303	27GPP	PYROMETER,AAA01001
6695012305978	14ABC	TRANSDUCERAAA01002
6695013633031	27EDA	TRANSDUCERAAA01001
7025011963702	74HA0	TRANSFER UAAA01002
1005007755578	75AAG	ADAPTER,RENOP01002
1005010086283	75A99	HOUSING,MENOP01002

END

DYNA-METRIC VERSION 4.6 PROBLEM PARTS REPORT

Base name	ONSHORE ?	Base NFMC goal	Base NFMC	LRU name (noun or NSN)	NFMC due to this LRU	PROBLEM ?	Expected Back-orders (EBOs)	Pipeline quantity	Input stock level	CANN ?	LRU #	Work Unit Code	QPA	Appl frac	Total aircraft which use this LRU
BASX	Y	4.5	18.0	2835011156111	18.00	Y	21.83	26.83	5	Y	L 59	24EBA	1	1.00	18
				2840013114795	18.00	Y	218.82	234.82	16	Y	L 64	27ECG	12	1.00	18
				6605012562380	18.00	Y	22.66	28.66	6	Y	L 155	74DF0	1	1.00	18
				1270013093077	17.23	Y	17.23	21.23	4	Y	L 12	74CE0	1	1.00	18
				1630013201448	16.11	Y	16.11	31.11	15	Y	L 32	13DBA	1	1.00	18
				5865013249103	13.63	Y	13.63	21.63	8	Y	L 115	76EG0	1	1.00	18
				4810010549843	11.84	Y	11.84	12.84	1	Y	L 89	46CB0	1	1.00	18
				F0110100	9.58	Y	9.58	10.58	1	Y	L 1	23100	1	1.00	18
				6615013619746	8.75	Y	8.75	14.75	6	Y	L 171	14AP0	1	1.00	18
				4810011530975	8.12	Y	8.12	11.12	3	Y	L 93	41AAB	1	1.00	18
				2915011911818	7.36	Y	14.72	16.72	2	Y	L 69	27GAX	2	1.00	18
				5826010124864	7.35	Y	7.35	9.35	2	Y	L 105	71AB0	1	1.00	18
				1660013632742	7.10	Y	7.10	9.10	2	Y	L 50	41ABN	1	1.00	18
				1680011689396	5.62	Y	5.62	7.61	2	Y	L 53	14DH0	1	1.00	18
				6115012465622	5.39	Y	5.39	8.37	3	Y	L 143	42AJ0	1	1.00	18
				1660013452115	5.21	Y	5.21	7.21	2	Y	L 49	41AAA	1	1.00	18
				1270012383662	5.16	Y	5.16	9.13	4	Y	L 11	74AP0	1	1.00	18
				6340011538696	4.83	Y	4.83	6.82	2	Y	L 151	64AD0	1	1.00	18
				5895011126380	4.23	N	4.23	8.18	4	Y	L 121	65AA0	1	1.00	18
				1680012649871	3.86	N	7.71	8.71	1	Y	L 56	14DP0	2	1.00	18
				1270992255327	3.63	N	3.63	6.58	3	Y	L 15	74BM0	1	1.00	18
				6130012099062	3.59	N	7.17	9.17	2	Y	L 147	42AN0	2	1.00	18
				1260012511150	3.41	N	3.41	7.31	4	Y	L 9	74KB0	1	1.00	18
				5826010121938	3.10	N	3.10	5.06	2	Y	L 104	71AA0	1	1.00	18
				5895012301284	3.07	N	3.07	5.02	2	Y	L 125	74LE0	1	1.00	18
				1290013223711	3.07	N	3.07	5.02	2	Y	L 16	75DJ0	1	1.00	18
				5985011469283	2.99	N	2.99	5.90	3	Y	L 133	76EW0	1	1.00	18
				6610011150131	2.80	N	2.80	4.74	2	Y	L 161	51AB0	1	1.00	18
				5895013080933	2.56	N	2.56	5.43	3	Y	L 128	76BC0	1	1.00	18

Appendix C: Aircraft Sustainability Model Version 3.0 Lean Level Computations

TABLE C.1

LEAN LEVEL COMPUTATION DATA

National Stock Number (NSN)	Demand Rate Per Flying Hour	Repair Cycle Time (Days)	Percent BaseRepair (PBR)	Condemn Rate	QPA
1270012383662	.00162	3.0	0.0	0.0	1
1270013093077	.00346	1.0	0.0	0.0	1
1290013223711	.00226	6.0	.37	0.0	1
1650011657203	.00037	6.0	0.0	0.0	4
1650012289276	.00050	6.0	0.0	0.0	1
1660013452115	.00049	5.0	0.0	0.0	1
1660013632742	.00058	2.0	0.0	0.0	1
1680011689396	.00064	4.0	0.0	0.0	2
2835011156111	.00239	5.0	.02	0.0	1
2840013114795	.00106	1.0	0.0	0.0	12
4320000620511	.00090	6.0	0.0	0.0	2
4810010549843	.00027	2.0	.12	0.0	1
4810010996392	.00050	4.0	1.0	0.0	1
5826010124864	.00028	5.0	0.0	0.0	1
5895011126380	.00268	6.0	0.0	0.0	1
5985011469283	.00090	6.0	0.0	0.0	1
5985012122950	.00186	6.0	.45	0.0	1
6115012465622	.00162	3.0	0.0	0.0	1
6130012099062	.00052	4.0	0.0	0.0	2
6340011538696	.00026	5.0	0.0	0.0	1
6610011150131	.00093	4.0	.07	0.0	1
6620012788027	.00042	6.0	0.0	0.0	1
6625011938861	.00099	1.0	0.0	0.0	4
5865013249103	.00652	6.0	0.0	0.0	1
6605012562380	.00541	4.0	0.0	0.0	1

(DMAS data file provided by HQ AFMC/LGIW)

TABLE C.2

STOCK LEVEL INPUT PARAMETERS

Parameter	30 Day MRSP	20 Day MRSP
Order and Ship Time	9 Days	3 Days
Percent Base Repair	Actual	Actual
Base Repair Time	Actual	Actual
Depot Repair Time	Actual	Actual
NRTS Condemn Time	Actual	Actual
ENMCS - Day 20/30	6.66	6.66
ENMCS - Day 10	3.42	3.42
Budget	$4,000,000	$2,666,666

Table C.3 illustrates the difference in stock levels between an MRSP configured for 30 days of supply with a nine day order and ship time and an MRSP configured for 20 days of supply with a three day order and ship time as computed by the ASM. With transportation available to and from the depot on day 21 of the war, there is a need for an MRSP configured for 20 days of supply only. Thus, the ASM calculated lean stock levels for a 20 day MRSP are used in this experiment instead of those necessary for a 30 day MRSP. If 30 day MRSP stock levels were used in this experiment, 118 units of unnecessary stock system-wide would have been included in the Dyna-METRIC 6.4 simulation and could have distorted the results.

TABLE C.3

LEAN LEVEL OUTPUT

NATIONAL STOCK NUMBER	BAS1 30 Day MRSP	LL BAS1 20 Day MRSP	BAS2 30 Day MRSP	LL BAS2 20 Day MRSP	BAS3 30 Day MRSP	LL BAS3 20 Day MRSP	BAS4 30 Day MRSP	LL BAS4 20 Day MRSP
1270012383662	3	1	0	0	1	0	0	0
1270013093077	5	3	9	6	5	3	6	4
1290013223711	4	3	4	2	0	0	0	0
1650011657203	5	4	6	4	4	3	5	4
1650012289276	3	3	3	3	2	1	3	2
1660013452115	4	3	4	3	3	3	4	3
1660013632742	3	3	3	3	3	2	3	2
1680011689396	3	2	3	2	4	4	2	2
2835011156111	8	6	7	5	11	9	6	5
2840013114795	39	31	34	27	46	37	34	27
4320000620511	6	5	7	5	8	6	6	5
4810010549843	2	2	2	2	2	2	2	2
4810010996392	0	0	0	0	0	0	0	0
5826010124864	3	2	3	2	3	2	2	2
5895011126380	5	4	6	5	8	7	5	4
5985011469283	3	3	4	3	5	4	3	3
5985012122950	3	2	5	3	2	1	3	2
6115012465622	4	4	4	4	6	5	4	3
6130012099062	4	4	4	3	5	4	4	3
6340011538696	3	2	2	2	3	2	2	2
6610011150131	3	3	4	3	4	4	4	3
6620012788027	4	3	4	4	3	3	4	3
6625011938861	10	8	11	9	12	10	10	8
5865013249103	0	0	0	0	17	13	10	8
6605012562380	0	0	0	0	2	1	7	2
Total	127	**101**	129	**100**	159	**126**	129	**99**
Stock Difference		**26**		**29**		**33**		**30**

AIRCRAFT SUSTAINABILITY MODEL VERSION 3.0 INPUT PARAMETERS

LEAN STOCK LEVEL DETERMINATION

Notes:

(1) The options used for this research are highlighted in bold print and explained in Tables C.4 through C.12.

(2) Only the Aircraft Sustainability Model Version 3.0 LRU records, parameter, and scenario files used in this research are addressed in this appendix. Further information can be obtained by referencing Aircraft Sustainability Model Version 1.5 Users Manual (Eichorn, 1989: A-1 - A-7).

(3) LRU records, parameter, and scenario file definitions are direct quotations from the Aircraft Sustainability Model Version 1.5 Users Manual (Eichorn, 1989: A-1 - A-7).

(4) The actual input LRU records for this experiment are included at the end of this appendix as well as an example of the *shop.lru* output report.

Design of Experiment

The data sample for this experiment is the top 25 problem parts for the F-16C Mission Design Series as identified by Dyna-METRIC Version 4.6 (Refer to Appendix B). These top 25 problem parts were compared to the HQ AFMC/XP worldwide critical item management program list for the F-16C and were found to be comparable parts.

The calculation of ASM levels for this research was completed in a manner so that the assumptions of the experiment and the assumptions made in the ASM model were

correlated with each other. Provided below is a summary of the assumptions used and an explanation of the LRU records, parameter, and scenario files used in the ASM stock level computations.

Assumptions:

(1) Only the top 25 problem LRUs are considered.

(2) Cost of individual LRUs are considered when procuring stock for the MRSP. The ASM procures stock in a manner which minimizes ENMCS subject to a budget constraint. This assumption is made to emulate real world constraints.

(3) The flying scenario used in the ASM model is the same flying scenario used in the Dyna-METRIC Version 4.6 and Version 6.4 models.

(4) Only MRSP assets are considered in this experiment.

(5) Stock levels will be computed based on a nine day and three day OST for 30 day and 20 day MRSPs, respectively.

LRU COMPONENT DATA

File: Prefix.1

Definition: Each LRU component in the MRSP will have a corresponding series of seven records in this file. These are read as FORTRAN free-format records with fields separated by a blank space and column, positioning is insignificant.

TABLE C.4

INPUT RECORD 1: LRU COMPONENT DATA

Record 1	Description
NSN	National Stock Number of the Component. **For this research, LRUs are identified by NSNs (Refer to Table C.1).**
COST	Unit Cost. **For this research, actual unit costs provided by the DMAS data file are input for all NSNs (Refer to Table A.1).**
IQPA	Quantity Installed per Aircraft. **For this research, actual QPA values provided by the DMAS data file are input for all NSNs (Refer to Table C.1).**
FAP	Future Application Fraction. The fraction of aircraft that will be configured with this NSN. **For this research, actual future application fraction values provided by the DMAS data file are input for all NSNs.**
PLTT	Procurement Lead-time in Months. **For this research, the ASM converter program generates a value of "12" based on actual values in the DMAS data file for all NSNs.**
ITASSE	Starting Asset Position. The starting asset position for the NSN before any buys are made by the Aircraft Sustainability Model. **For this research, a value of "0" is input for all NSNs.**
NHANSN	NSN of the Next Higher Assembly. The next higher assembly for LRUs will be the weapon system. **For this research, 0F016 is input for all NSNs.**

IBUDCODE	Budget Code. A budget code integer from 1 to 9 that permits cost subtotals to be generated by budget code. 1 = LRU with SRUs. 2 = LRU without SRUs. **For this research, a value of "2" is input for all NSNs.**
NEGLV	Negotiated Level for this NSN. Sometimes, requirements levels are set without regard for optimization. If NEGFLAG [in the parameters (PARAMS) file] is set to "T" - true, the model will always buy NEGLV of the item. T indicates purchase of NEGLV quantity as a floor. **For this research, NEGFLAG in the PARAMS file is set to "F", indicating false and a value of "0" is input for NEGLV for all NSNs.**
MAINTCON	Maintenance Type. Specifies whether the LRU is RR or RRR. This affects when wartime LRU base repair begins. **For this research, "RR" is input for all NSNs.**
ITEMPBUY	Item Pipeline Buy. Fraction of the pipeline to be bought sacrosanct for this component. This value is used only if the PBUYA field on the PARAMS file is coded "ITEM". **For this research, a value of "0" is input for all NSNs.**
CANNFLAG	Cannibalization Identifier. N = Item may not be cannibalized. Y = Item may be cannibalized. This value is only used if the CANN field of the PARAMS file is coded "P" for partial cannibalization. **For this research, "Y" is input for all NSNs.**
NRTSDEC	NRTS Decision. 0 = Decision to ship component to the next higher servicing facility is made after attempting repair. 1 = Decision to ship component to the next higher servicing facility is made before attempting repair **For this research, a value of "1" is input for all NSNs.**

TABLE C.5

INPUT RECORD 2: LRU COMPONENT DATA

Record 2	Description
IBRPT	Peacetime Base Repair Time (in days). **For this research, actual peacetime base repair times provided by the DMAS data file are input for all NSNs (Refer to Table C.1).**
IBRTW	Wartime Base Repair Time (in days). **For this research, actual wartime base repair times provided by the DMAS data file are input for all NSNs (Refer to Table C.1).**

TABLE C.6

INPUT RECORD 3: LRU COMPONENT DATA

Record 3	Description
IOSTP	Peacetime Order and Ship Time (in days). **For this research, a value of "9" is input for 30 day MRSP stock level computations and a value of "3" is input for 20 day MRSP stock level computations.**
IOSTW	Wartime Order and Ship Time (in days). **For this research, a value of "9" is input for 30 day MRSP stock level computations and a value of "3" is input for 20 day MRSP stock level computations.**

TABLE C.7

INPUT RECORD 4: LRU COMPONENT DATA

Record 4	Description
IDRTP	Peacetime Depot Repair Time (in days). **For this research, actual peacetime depot repair times provided by the DMAS data file are input for all NSNs.**
IDRTW	Wartime Depot Repair Time (in days). **For this research, actual wartime depot repair times provided by the DMAS data file are input for all NSNs.**

TABLE C.8

INPUT RECORD 5: LRU COMPONENT DATA

Record 5	Description
TOIMDRP	Peacetime Demand Per Flying Hour. **For this research, actual peacetime demand per flying hour values provided by the DMAS data file are input for all NSNs (Refer to Table C.1).**
TOIMDRW	Wartime Demand Per Flying Hour. **For this research, actual wartime demand per flying hour values provided by the DMAS data file are input for all NSNs (Refer to Table C.1).**

TABLE C.9

INPUT RECORD 6: LRU COMPONENT DATA

Record 6	Description
BNRTSP	Peacetime Base Not Reparable This Station Rate. Peacetime percentage of demands that are either condemned or sent to the depot for repair (overhaul) for this component. **For this research, actual peacetime base NRTS rates provided by the DMAS data file are input for all NSNs (Refer to Table C.1 for PBR rates).**
BNRTSW	Wartime Base Not Reparable This Station Rate. Wartime percentage of demands that are either condemned or sent to the depot for repair (overhaul) for this component. **For this research, actual wartime base NRTS rates provided by the DMAS data file are input for all NSNs (Refer to Table C.1 for PBR rates).**

TABLE C.10

INPUT RECORD 7: LRU COMPONENT DATA

Record 7	Description
CONPCTP	Peacetime Condemnation Fraction. **For this research, actual peacetime base condemnation rates provided by the DMAS data file are input for all NSNs (Refer to Table C.1).**
CONPCTW	Wartime Condemnation Fraction. **For this research, actual wartime base condemnation rates provided by the DMAS data file are input for all NSNs (Refer to Table C.1).**

PARAMETERS FILE

File: **Prefix.PRM**

Definition: The parameters file contains all of the processing options for a particular ASM run such as the weapon system name, the flying program for the scenario, the day to be analyzed, the direct support objective (DSO), the first day that base repair of LRUs is permitted, and type of computer on which the model run is being made (PC for personal computer). The DDD in the file name is the day(s) in the days of analysis card. The parameters in each file are determined by the ENMCS objectives on the Option 25 card. The following records are read as FORTRAN free-format records. In this file, each field must be on a separate line.

TABLE C.11

INPUT RECORD : PARAMETERS FILE

Record	Description
ITODAY	Day of Analysis. Must be between 0 and 99. May specify a first and second day of analysis. **For this research, values of "10" and "20" are input for 20 day MRSP computations and values of "10" and "30" are input for 30 day MRSP computations.**
DATADIR	ASM Input Data Drive/Directory. **For this research, C:\ASM\DATA is input.**
OUTPDIR	ASM Output Data Drive/Directory. **For this research, C:\ASM\OUTPUT is input.**
DEBUGER	Debug Option. Specifies the extent to which debug output should be printed. Must be FULL, SOME, NONE, or NSNs; defaults to NONE. **For this research, "NONE" is input.**
PIPEFLAG	Pipeline Quantity Option. Specifies whether the computed pipeline quantities will be written to the OUTPIPE file. Must by T or F; defaults to T. **For this research, "T" is input.**

CANN	Cannibalization Identifier. Specifies the type of cannibalization allowed. F = All items are cannibalized. N = None of the items are cannibalized. P = Items coded "Y" in the CANNFLAG of the component data files may be cannibalized. **For this research, "F" is input.**
NEGFLAG	Negotiated Level Flag. Specifies whether the model is to treat NEGLV as a sacrosanct level. Must be T or F. T = indicates purchase of NEGLV quantity as a floor. F = indicates ignore NEGLV quantity. **For this research, "F" is input.**
EXPRESUP	Resupply Type. Specifies that resupply is exponential rather than deterministic. T = Exponential Resupply F = Deterministic Resupply **For this research, "F" is input.**
OPTMTHD	Optimization Method. C = Confidence Level Optimization Method. E = ENMCS Optimization Method. M = ENMCS/EBO Optimization Method. **For this research, "E" is input.**
BUYPEAK	Peak Pipeline Buy Option. Specifies whether the peak pipelines for the whole scenario (T), the peak pipelines through a specified day (for example, 30), or the pipelines on the day to be analyzed (F) are to be bought sacrosanct to the level specified by PBUY (see below). **For this research, "T" is input.**
COMPUTER	Host Computer. Identifies host computer for the ASM. Should be set to "PC" for any microcomputer. **For this research, "PC" is input.**

VMOPTION	Variance-to-Mean Ratio Computation Option. Specifies how the variance-to-mean ratio (VMR) computation is to be performed. May be 1, 2, 3, or 4 ,but anything greater than 1 (fixed VMR) is highly experimental. 1 = CONSTANT 2 = AFMC 3 = VARI 4 = SHERBROOKE **For this research, a value of "1" is input.**
Q	VMR Value. For VMOPTION = 1, it specifies the constant VMR. Must be at least 1.0. **For this research, a value of "1.0" is input.**
PBUYA	Percent Pipeline Buy Option. Specifies the percentage of the pipeline to be bought sacrosanct; either peak or for ITODAY, see BUYPEAK. A value of 1.0 would specify buy the whole pipeline, 0.5 would buy half, 0.0 would buy none. PBUYA consists of two numbers: the first is the value for LRUs, the second for SRUs. A value of "ITEM" may also be used to indicate that the percentage coded in ITEMBUY on the component data files will be bought sacrosanct. A value of "QPA" overrides the ITEMBUY field and buys the floor quantity for items with QPA > 2. **For this research, "ITEM" is input.**
WSNAME	Weapon System Name. **For this research, "F016C" is input.**
NUNITS	Number of Units of the Weapon System at each Base (PAA). **For this research, a value of "18" is input.**
NBASES	Number of Bases. **For this research, a value of "1" is input. ASM can only analyze one base at a time.**

NFIRSTBR	Base Repair Switch. Identifies the first day base repair is allowed. Base component repair is suspended for days 1 through NFIRSTBR - 1. NFIRSTBR is an array of three numbers: NFIRSTBR (1) is the first day that RR LRUs are repaired. NFIRSTBR (2) is the first day that RRR LRUs are repaired. NFIRSTBR (3) is the first day that SRUs are repaired. **For this research, values of "31," "3," and "31" are input respectively, for 30 day MRSP computations and values of "21," "3," and "21" are input respectively, for 20 day MRSP computations.**
NFIRSTDR	Depot Repair Switch. Identifies the first day depot repair is allowed. Depot component repair is suspended for days 1 through NFIRSTDR - 1. NFIRSTDR is an array of three numbers: NFIRSTDR (1) is the first day that RR LRUs are repaired. NFIRSTDR (2) is the first day that RRR LRUs are repaired. NFIRSTDR (3) is the first day that SRUs are repaired. **For this research, values of "0," "0," and "0" are input respectively, for 20 day and 30 day MRSP computations.**
NFIRSTOS	Transportation from the Depot Start Date. The first day that shipment from the depot becomes available. **For this research, a value of "21" is input for 20 day MRSP computations and a value of "31" is input for 30 day MRSP computations.**
DSO	Direct Support Objective. The number of not mission capable for supply (NMCS) aircraft allowed. The model optimizes the probability that the number NMCS is not greater than the DSO. May input dual DSO's corresponding to dual days of analysis. **For this research, a value of "3.42" is input for day 10 of analysis and a value of "6.66" is input for day 20 and day 30 of analysis.** **3.42 = 81% Aircraft Availability and 6.66 = 63% Aircraft Availability.**

SCENARIO FILE

File: Prefix.SC

Definition: The scenario file contains specific items about the flying-hour program for an ASM run. These are read as FORTRAN free-format records. In this file, each field must be on a separate line.

TABLE C.12

INPUT RECORD : SCENARIO FILE

Record	Description
NDAYSFH	Final Flying Hour Change Date. The last day for which the flying program will change. The flying program is specified for day 0 through day NDAYSFH. (See the next field, FHP.) The flying programs on days before day 0 are assumed identical to day 0. The flying programs on days after day NDAYSFH are assumed to be identical to day NDAYSFH. **For this research, a value of "20" is input for 20 day MRSP computations and a value of "30" is input for 30 day MRSP computations.**
FHP	Flying Hour Program. The array of the flying-hour program in hours per day, for days 0 through NDAYSFH. **For this research, the same flying hour program input for Dyna-METRIC Version 4.6 computations is used (Refer to Tables B.9 and B.10).**

LEAN LEVEL COMPUTATION

SAMPLE AIRCRAFT SUSTAINABILITY MODEL VERSION 3.0
INPUT LRU RECORD FILE

```
1270012383662  258447.00 1  1.00  12.0  0 0F016EC28  2  0 RR  0.00 Y AAA 1.00
     6     6
     3     3
    27    27
 0.00491 0.00491
 0.80000 0.80000
 0.00000 0.00000
1270013093077  125368.00 1  1.00  12.0  0 0F016EC28  2  0 RR  0.00 Y AAA 1.00
     1     1
     3     3
    56    56
 0.00346 0.00346
 1.00000 1.00000
 0.01000 0.01000
1290013223711  176194.00 1  1.00  12.0  0 0F016EC28  2  0 RR  0.00 Y AAA 1.00
     6     6
     3     3
     3     3
 0.00226 0.00226
 0.63000 0.63000
 0.00000 0.00000
1650011657203   43632.00 4  1.00  12.0  0 0F016EC28  2  0 RR  0.00 Y AAA 1.00
     6     6
     3     3
    38    38
 0.00037 0.00037
 1.00000 1.00000
 0.02000 0.02000
1650012289276   44178.00 1  1.00  12.0  0 0F016EC28  2  0 RR  0.00 Y ADJ 1.00
     6     6
     3     3
    47    47
 0.00050 0.00050
 1.00000 1.00000
 0.00000 0.00000
1660013452115     7549.00 1  1.00  12.0  0 0F016EC28  2  0 RR  0.00 Y AAA 1.00
     5     5
     3     3
   115   115
 0.00049 0.00049
 1.00000 1.00000
 0.00000 0.00000
1660013632742   14424.00 1  1.00  12.0  0 0F016EC28  2  0 RR  0.00 Y AAA 1.00
     2     2
     3     3
   125   125
 0.00058 0.00058
 1.00000 1.00000
 0.00000 0.00000
```

```
1680011689396    4427.00 1  1.00  12.0  0 0F016EC28  2  0 RR  0.00 Y AAA 1.00
     4     4
     3     3
    96    96
 0.00064 0.00064
 1.00000 1.00000
 0.00000 0.00000
2835011156111    4349.00  1  1.00  12.0  0 0F016EC28  2  0 RR  0.00 Y AAA 1.00
     5     5
     3     3
    27    27
0.00239 0.00239
 0.98000 0.98000
 0.13720 0.13720
2840013114795     999.00 12  1.00  12.0  0 0F016EC28  2  0 RR  0.00 Y AAA 1.00
     1     1
     3     3
    29    29
 0.00106 0.00106
 1.00000 1.00000
 0.26000 0.26000
4320000620511    8723.00  2  1.00  12.0  0 0F016EC28  2  0 RR  0.00 Y AAA 1.00
     6     6
     3     3
    24    24
 0.00090 0.00090
 1.00000 1.00000
 0.04000 0.04000
4810010549843    7637.00  1  1.00  12.0  0 0F016EC28  2  0 RR  0.00 Y AAA 1.00
     2     2
     3     3
   398   398
 0.00027 0.00027
 0.88000 0.88000
 0.00000 0.00000
4810010996392    8728.00  1  1.00  12.0  0 0F016EC28  3  0 RR  0.00 Y NOP 1.00
     4     4
     3     3
    31    31
 0.00050 0.00050
 0.00000 0.00000
 0.00000 0.00000
5826010124864     4040.00 1  1.00  12.0  0 0F016EC28  2  0 RR  0.00 Y AAA 1.00
     5     5
     3     3
   248   248
 0.00028 0.00028
 1.00000 1.00000
 0.00000 0.00000
5865013249103    55939.00 1  1.00  12.0  0 0F016EC28  2  0 RR  0.00 Y AAA 1.00
     6     6
     3     3
     3     3
 0.00652 0.00652
 1.00000 1.00000
 0.00000 0.00000
```

```
5895011126380    33116.00 1  1.00  12.0  0 0F016EC28  2  0 RR  0.00 Y AAA 1.00
     6     6
     3     3
    31    31
 0.00268 0.00268
 1.00000 1.00000
 0.00000 0.00000
5985011469283     8901.00 1  1.00  12.0  0 0F016EC28  2  0 RR  0.00 Y AAA 1.00
     6     6
     3     3
    56    56
 0.00090 0.00090
 1.00000 1.00000
 0.00000 0.00000
5985012122950   127757.00 1  1.00  12.0  0 0F016EC28  2  0 RR  0.00 Y AAA 1.00
     6     6
     3     3
    31    31
 0.00186 0.00186
 0.55000 0.55000
 0.00550 0.00550
6115012465622    16122.00 1  1.00  12.0  0 0F016EC28  2  0 RR  0.00 Y AAA 1.00
     3     3
     3     3
    28    28
 0.00162 0.00162
 1.00000 1.00000
 0.07000 0.07000
6130012099062     8227.00 2  1.00  12.0  0 0F016EC28  2  0 RR  0.00 Y AAA 1.00
     4     4
     3     3
    28    28
 0.00052 0.00052
 1.00000 1.00000
 0.09000 0.09000
6340011538696     3880.00 1  1.00  12.0  0 0F016EC28  2  0 RR  0.00 Y AAA 1.00
     5     5
     3     3
   197   197
 0.00026 0.00026
 1.00000 1.00000
 0.00000 0.00000
6605012562380   140732.00 1  1.00  12.0  0 0F016EC28  2  0 RR  0.00 Y AAA 1.00
     4     4
     3     3
    49    49
 0.00541 0.00541
 1.00000 1.00000
 0.00000 0.00000
6610011150131    13117.00 1  1.00  12.0  0 0F016EC28  2  0 RR  0.00 Y AAA 1.00
     4     4
     3     3
    25    25
 0.00093 0.00093
 0.93000 0.93000
 0.03720 0.03720
```

```
6620012788027      4788.00 1   1.00   12.0   0 0F016EC28   2   0 RR   0.00 Y AAA 1.00
     6      6
     3      3
    53     53
 0.00042 0.00042
 1.00000 1.00000
 0.02000 0.02000
6625011938861     27700.00 4   1.00   12.0   0 0F016EC28   2   0 RR   0.00 Y AAA 1.00
     1      1
     3      3
    41     41
 0.00099 0.00099
 1.00000 1.00000
 0.00000 0.00000
```

SAMPLE AIRCRAFT SUSTAINABILITY MODEL OUTPUT REPORT - *shop.lru*

LRU SHOPPING LIST FOR DAY 20

EC28.F016C Davila-Martinez/Bollinger Data Set for Day20 LL -NNFETITEM
FOR THE "0F016EC28 " SYSTEM, FOR THE 20th DAY

COMPONENT NAME	COST	TARGET	NUMBER BOUGHT	LEVEL	BUDGET CODE
1270012383662	258447.00	0	0	1	2
1270013093077	125368.00	3	3	1	2
1290013223711	176194.00	0	0	1	2
1650011657203	43632.00	3	1	1	2
1650012289276	44178.00	1	0	1	2
1660013452115	7549.00	3	1	1	2
1660013632742	14424.00	2	0	1	2
1680011689396	4427.00	4	1	1	2
2835011156111	4349.00	9	2	1	2
2840013114795	999.00	37	10	1	2
4320000620511	8723.00	6	1	1	2
4810010549843	7637.00	2	1	1	2
4810010996392	8728.00	0	0	1	3
5826010124864	4040.00	2	0	1	2
5865013249103	55939.00	13	4	1	2
5895011126380	33116.00	7	3	1	2
5985011469283	8901.00	4	1	1	2
5985012122950	127757.00	1	1	1	2
6115012465622	16122.00	5	1	1	2
6130012099062	8227.00	4	1	1	2
6340011538696	3880.00	2	0	1	2
6605012562380	140732.00	1	1	1	2
6610011150131	13117.00	4	1	1	2
6620012788027	4788.00	3	1	1	2
6625011938861	27700.00	10	3	1	2

Appendix D: Dyna-METRIC Version 6.4 Simulation Model

DYNA-METRIC VERSION 6.4 INPUT PARAMETERS

Notes:

(1) The options used for this research are highlighted in bold print and explained in Tables D.1 through D.16.

(2) Only the Dyna-METRIC Version 6.4 header records and columns used in this research are addressed in this appendix. Further information can be obtained by referencing Dyna-METRIC Version 6, An Advanced Capability Assessment Model (Isaacson and Boren, 1993: 45-90).

(3) Header records and column definitions are direct quotations from the Dyna-METRIC Version 6 Handbook (Isaacson and Boren, 1993: 45-90).

(4) The actual input parameter records and data files for this experiment are included at the end of this appendix as well as an example of a portion of the pipeline report output.

ADMINISTRATIVE DATA

Header Record: NONE

Definition: Provides general information about the run, including heading, number of trials, wartime start, days of analysis, and seeds for the random number generator. It also provides the administrative delay times for each echelon (base and depot). Table D.1, D.2, and D.3 will summarize the data inputs for the second, third, and fourth record of this input file. The first record is simply a heading for the entire input data file.

TABLE D.1

INPUT RECORD: ADMINISTRATIVE DATA (SECOND RECORD)

Column	Description
1	Cutoff Direction Switch 0 = Cutoff parameters in the BASE and TRNS record groups apply to forward transportation only. 1 = Cutoff parameters in the BASE and TRNS record groups apply to both forward and retrograde transportation. **For this research, a value of "1" is input.**
3-7	Base Administrative Time The deterministic delay (in days) experienced by LRUs removed at the flight line prior to entering base level repair. **For this research, a value of "1" is input.**
13-17	Depot Administrative Time The deterministic delay (in days) experienced by LRUs and SRUs that have been NRTSed to the depot from bases and CIRFs, after arrival at the depot and prior to entering depot level repair. **For this research, a value of "5" is input.**
20-30	Data Set Version Must contain "Version 6.4" to correctly identify the input data set. **For this research, "Version 6.4" is input.**
67-70	Number of Trials. This is the number of model iterations to run. Limited by parameter DMTRIES. **For this research, a value of "1" is input. However, 20 iterations of each scenario is run.**

TABLE D.2

INPUT RECORD: ADMINISTRATIVE DATA (THIRD RECORD)

Column	Description
1-80	<u>Random Number Seeds.</u> Random number seeds are needed for the various random number streams that control the generation of removals, repair times, transportation times, NRTS actions etc. **For this research, the random numbers are altered for each of 20 trial runs per scenario.**

TABLE D.3

INPUT RECORD: ADMINISTRATIVE DATA (FOURTH RECORD)

Column	Description
1-4	<u>First Day of War.</u> Independent of the first day of analysis and must be greater than 0. Wartime resupply times and demand rate changes go into effect on this day. **For this research, a value of "1" is input.**
5-8	<u>Times of Analysis</u> These are the days for which output reports are requested. **For this research, a consecutive 30 days of *data.pipe* reports are required. Values of "20 through 49" are input.**

OPTION SELECTION

Header Record: OPT

Definition: Defines the options that generate Dyna-METRIC's reports and control lateral supply.

TABLE D.4

INPUT RECORD: OPTION SELECTION

Column	Description
5-7	Option Number (requests output reports). **For this research, the following option is used:** **15 Pipeline Report:** **Produces an output called *data.pip* containing the expected pipeline segment contents for each component by location and day of analysis.**
8-10	Parameters First Parameter: 0 = Report both LRUs and SRUs. 1 = Report LRUs only. **For this research, a value of "1" is input.**

DEPOT DESCRIPTION

Header Record: DEPT

Definition: Provides characteristics about each depot, including its resupply availability and when unconstrained repair of LRUs and SRUs starts. The number of depots may not exceed DMDEPOTS.

TABLE D.5

INPUT RECORD: DEPOT DESCRIPTION

Column	Description
1-4	Depot Name. The name of the depot. May not be a header (such as "DEPT") or the name of another location (base, CIRF, or depot). **For this research, one depot is used and named "DEPO".**
35-39	Resupply Start. Day resupply of parts ordered from an outside supplier becomes available. **For this research, a value of "21" is input.**
40	Allocation Switch. 0 = Allocate spares among all bases and CIRFs, including any cut off from the depot. 1 = Do not allocate spares for presently cutoff bases and CIRFs. . **For this research, a value of "1" is input.**
51-55	Repair Start for Unconstrained LRUs. This is the day the depot starts repairing LRUs not assigned to a repair resource in the TPRT records. **For this research, a value of "1" is input.**
61-65	Repair start for Unconstrained SRUs. This is the day the depot starts repairing SRUs not assigned to a repair resource in the TPRT records. **For this research, a value of "1" is input.**
66	SRU Cannibalization Switch. 0 = Depot does not cannibalize SRUs. 1 = Depot cannibalizes SRUs between identical LRUs that are AWP. **For this research, a value of "1" is input.**

BASE DESCRIPTION

Header Record: BASE

Definition: Provides characteristics about each base, including its link to a CIRF (if any), resupply availability, and when unconstrained repair of LRUs and SRUs starts. A record is required for each base. The number of bases may not exceed DMBASES.

TABLE D.6

INPUT RECORD: BASE DESCRIPTION

Column	Description
1-4	Base Name. The name of the base. May not be a header (such as "BASE") or the name of another location **For this research there are four (4) bases. The names of the bases are as follows: "BAS1", "BAS2", "BAS3", and "BAS4".**
35-39	Resupply Start. Day resupply of parts ordered from a supplier other than the CIRF or depot first becomes available. **For this research, a value of "21" is input for each of the four bases.**
51-55	Repair Start for Unconstrained LRUs. This is the day the base can start repairing LRUs that are not assigned to a repair resource in the TPRT records. **For this research, a value of "21" is input.**
76	Queue Damage Indicator. 0 = Repair queue is not lost. 1 = Contents of the base's repair queue are lost on the first day of war. **For this research, a value of "1" is input.**
80	Special/Regular Switch. Specifies whether the special or regular component demand rates apply to the base. 0 = Regular Base. 1 = Special Base. **For this research, a value of "0" is input.**

DEPOT TRANSPORTATION

Header Record: TRNS

Definition: Describes the transportation resources connecting bases and CIRFs with depots. If a record in not entered for some location directly connected to a depot, transportation between the two is assumed to be instantaneous and never cut off.

TABLE D.7

INPUT RECORD: DEPOT TRANSPORTATION

Column	Description
1-4	Base Name. **For this research, the base names indicated in Table D.6 are input.**
6-9	Depot Name. **For this research all bases use the services of a single depot (DEPO).**
11-15	Transportation Time to Depot. Number of days required to ship an unserviceable part from the base location to the depot. **For this research, transportation times to the depot will be varied to reflect the appropriate scenario ("3.0", "3.5", or "4.0" days).**
17-21	Transportation Time from Depot. Number of days required to ship a serviceable part from the depot to the base location. **For this research, transportation times from the depot will be varied to reflect the appropriate scenario ("3.0", "3.5", "4.0" days).**
25-29	Transportation Start. The day that transportation from the depot first becomes available. **For this research , a value of "21" is input.**

AIRCRAFT LEVELS

Header Record: ACFT

Definition: Specifies the number of aircraft assigned to each base. A base with no ACFT record is assigned no aircraft.

TABLE D.8

INPUT RECORD: AIRCRAFT LEVELS

Column	Description
1-4	Base Name. The name of the base for which aircraft levels are specified. Must be named in the BASE record group. Enter at most one record per base. **For this research, each of the four bases identified in Table D.6 are used.**
5-8	First Aircraft Level. Number of aircraft at the base. Levels may change as many as DMCHANGE times during the scenario. Not all levels must be used; the last level specified carries throughout the rest of the scenario. The total number of aircraft across all locations may not exceed DMAIRCFT. **For this research, each of the four bases are assigned "18" aircraft.**

SORTIE RATES

Header Record: SRTS

Definition: Specifies the average daily number of sorties required per aircraft at each base. Aircraft at bases with no associated SRTS record do not fly sorties.

TABLE D.9

INPUT RECORD: SORTIE RATES

Column	Description
1-4	Base Name. The name of the base for which sortie requirements are specified. Must be named in the BASE record group. Enter at most one record per base. **For this research, a record is established for each base: BAS1, BAS2, BAS3, and BAS4.**
5-8	First Sortie Rate. The number of daily sorties per aircraft, which may not exceed the turn rate on the base's TURN record. Rates may change DMCHANGE times during the scenario. Not all rates must be used. The last rate specified carries throughout the rest of the scenario. **For this research, a value of "2.6" is input for the first sortie rate.**
9-12	Day Second Rate Starts. The day a rate starts must be greater than the day the previous rate started. **For this research, the second sortie rate starts on day 6.**
13-16	Second Sortie Rate. **For this research, a value of "2.1" is input for the second sortie rate.**
17-20	Day Third Rate Starts. **For this research, the third sortie rate starts on day 11.**
21-24	Third Sortie Rate. **For this research, a value of "1.2" is input for the third sortie rate.**
25-28	Day Fourth Rate Starts. **For this research, the fourth sortie rate starts on day 14.**
29-32	Fourth Sortie Rate. **For this research, a value of "1.1" is input for the fourth sortie rate.**

FLYING HOURS PER SORTIE

Header Record: FLHR

Definition: Specifies the number of flying hours required per sortie at each base. Aircraft at bases with no FLHR record fly sorties of one hour each.

TABLE D.10

INPUT RECORD: DATA FLYING HOURS PER SORTIE

Column	Description
1-4	Base Name. The name of the base for which flying hours per sortie are specified. Must be named in the BASE record group. Enter at most one record per base. **For this research, a record is established for each base: BAS1, BAS2, BAS3, and BAS4.**
5-8	First Flying Hour Level. The number of flying hours per sortie per day. Flying hour levels may change as many as DMCHANGE time during the scenario. Not all levels must be used; the last level specified carries throughout the rest of the scenario. **For this research, flying hours vary based on the scenario being modeled. A value of "1.5" or "3" is input. Identical flying hour programs are input for all four bases.**

MAXIMUM SORTIE RATES

Header Record: TURN

Definition: Specifies the maximum number of sorties a mission capable aircraft can fly per day at each base. Aircraft at bases with no TURN records do not fly sorties.

TABLE D.11

INPUT RECORD: MAXIMUM SORTIE RATES

Column	Description
1-4	Base Name. The name of the base for which the maximum sortie rates are specified. Must be named in the BASE record group. Enter at most one record per base. **For this research, a record is established for each base: BAS1, BAS2, BAS3, and BAS4..**
5-8	First Maximum Sortie Rate. The maximum number of daily sorties per mission capable aircraft. Should be larger than the sortie rates on SRTS record. Rates may change as many as DMCHANGE times during the scenario. Not all "turn rates" must be used; the last rate specified remains throughout the scenario. **For this research, a value of "3.2" is input for the first maximum sortie rate.**
9-12	Day Second Rate Starts The day a rate starts must be greater than the day the previous rate started. **For this research, the second maximum sortie rate starts on day 11.**
13-16	Second Maximum Sortie Rate **For this research, a value of "2.6" is input for the second maximum sortie rate.**

LRU DESCRIPTION

Header Record: LRU

Definition: Describes the failure, repair, and resupply characteristics of each LRU. A pair of these records is required for each LRU. The number of LRUs may not exceed DMLRUS.

TABLE D.12

INPUT RECORD: LRU DESCRIPTION (FIRST RECORD)

Column	Description
1-16	LRU Name. Unique LRU identifier, such as NSN. May not be the name of another part and may not begin with a header word (such as "LRU"). **For this research, LRUs are identified by NSNs.**
18-21	Depot Name. The name of the depot that repairs the LRU. Leave blank if the LRU is not repaired by a depot. **For this research, the depot is referenced by "DEPO".**
23	Level of Repair. 1 = LRU can be repaired at a base, CIRF, or depot. 2 = LRU can only be repaired at a CIRF or depot. 3 = LRU can only be repaired at a depot. **For this research, a value of "1" is input.**
25	CIRF Reparability Switch. Allows the CIRF to be a special facility that repairs only a subset of LRUs in analyses where both base and depot have repair capabilities. 0 = CIRF cannot repair the LRU. 1 = CIRF can repair the LRU (if level of repair is not 3). **For this research, a value of "0" is input.**
26-28	Quantity per Aircraft (QPA). Number installed per aircraft. **For this research, actual QPA values provided by the DMAS data file are used for all NSNs (Refer to Table A.1).**

29-31	Minimum quantity. Minimum quantity of the LRU required for the aircraft to be mission capable. **For this research, the minimum quantity is always equal to the value in column 26-28 of this record.**
32	Sorties/Flying Hours Indicator. 0 = Demand rates are per flying hour. 1 = Demand rates are per sortie. **For this research, a value of "0" is input.**
33	Maintenance Procedure. Determines when the decision is made to NRTS or condemn the LRU and when its failed SRUs are detected. 0 = Wait until after attempting repair to make decision (in effect, delay the decision one repair time + time awaiting maintenance). 1 = Before attempting repair, make decision. **For this research, a value of "1" is input.**
34-40	Demand Rate at Special Bases. The expected demands per sortie or flying hour in peacetime at special bases (set on the BASE records). **For this research, actual values provided by the DMAS data files are input. Refer to the demand rates per flying hours outlined in Table B.1.**
41-47	Demand Rate at Regular Bases. The expected demands per sortie or flying hour in peacetime at regular bases (set on the BASE records). **For this research, actual values provided by the DMAS data file are input. Refer to the demand rates per flying hours outlined in Table B.1.**
48-52	Lone Base Repair Time (in days). The number of days to repair the LRU at bases not served by a CIRF. **For this research, actual values provided by the DMAS data file are input. Refer to the base repair times outlined in Table B.1.**

54-57	Lone Base NRTS Rate. Proportion of LRUs arriving for repair at bases not served by a CIRF that are sent to a higher echelon for repair. **For this research, actual values provided by the DMAS data file are input. Refer to the Percent Base Repair outlined in Table B.1.**
59-62	Lone Base Condemnation Rate Proportion of LRUs that are condemned at bases not served by a CIRF. **For this research, actual values are input. Refer to the Base Condemnation Rates outlined in Table B.1.**

TABLE D.13

INPUT RECORD: LRU DESCRIPTION (SECOND RECORD)

Column	Description
1-16	LRU Name. Must match LRU name given on the first record of the pair. **See column 1-16 of the first record of LRU description.**
32-36	Depot Repair Time. Number of days required to repair the LRU at the depot. **For this research, actual values provided by the DMAS data file are input.**
43-46	Depot Condemnation Rate. Proportion of LRUs that are condemned at the depot. **For this research, actual values provided by the DMAS data file are input.**
47-51	Peacetime Resupply Time (in days). The expected time for the highest echelon repairing the LRU to procure a replacement during peacetime. **For this research, actual values provided by the DMAS data file are input.**
75	No Cannibalization Indicator. 0 = LRU can be cannibalized. 1 = LRU cannot be cannibalized. **For this research, a value of "0" is input.**

APPLICATION FRACTIONS

Header Record: APPL

Definition: Specifies the proportion of each base's aircraft on which the LRU is installed. An LRU is considered to be installed on all aircraft at bases for which application fractions are not specified.

TABLE D.14

INPUT RECORD: APPLICATION FRACTIONS

Column	Description
1-16	LRU Name. The name of the LRU for which application fraction data are specified. Must be named in the LRU record group. Enter as many records as needed per LRU. **For this research, LRUs are identified by their NSNs.**
18-21	First Base Name Name of the first base to which the first application fraction applies. **For this research, the base names indicated in Table D.6 are input.**
22-26	First Application Fraction. Fraction of the aircraft stationed at the first base that contain the LRU. **For this research, a value of "1" is input.**

VARIANCE-TO-MEAN

Header Record: VTM

Definition: For LRUs, specifies wartime adjustment factors, the variance-to-mean ratio of the removal process, and the probability of repair resource with a backordered module. Parts for which these records are not given are assumed to have a Poisson removal process, to have wartime demand rates equal to peacetime rates, to be repairable on a repair resource with a backordered module if assigned to constrained repair, and to have sustained demand rates of zero.

TABLE D.15

INPUT RECORD: VARIANCE-TO-MEAN DATA

Column	Description
1-16	Part Name. The name of the LRU for which variance-to-mean data are specified. Must be named in the LRU record group. Enter at most one record per LRU. **For this research, LRUs are identified by their NSNs.**
20-23	Wartime Adjustment Factor for Special Bases. A number multiplied by the peacetime demand rate (in the LRU record group) to obtain the wartime demand rate. **For this research, actual values provided by the DMAS data files are input. All LRUs are assigned a value of "1".**
25-28	Wartime Adjustment Factor at Regular Bases. A number multiplied by the peacetime demand rate (in the LRU record group) to obtain the wartime demand rate. **For this research, actual values provided by the DMAS data files are input. All LRUs are assigned a value of "1".**
30-33	Variance-to-mean Ratio (of LRU removal process). <1 = Binomial Distribution. 1 = Poisson Distribution. >1 = Negative Binomial Distribution. **For this research, actual values provided by the DMAS data files are input. All LRUs are assigned a value of "1".**

STOCK LEVELS

Header Record: STK

Definition: Specifies each part's stock level at each location (depots, CIRFs, and bases). A stock level for a location reflects the number of serviceables and unserviceables on-hand and in transit to the location, less the number due out (or committed) to a forward location; it is not simply the number on the shelf. If all stock levels for a component were summed across all locations, the resulting number would be the number of assets in the entire system less those installed on aircraft.

TABLE D.16

INPUT RECORD: STOCK LEVELS

Column	Description
1-16	Part Name. Name of the LRU to which the stock levels apply. Must be named in the LRU record group. Enter as many records as needed per part. **For this research, parts are identified by their NSNs.**
18-21	First Stock Location. Name of the location to which first stock level applies. **For this research, the "DEPO" is input.**
22-26	First Stock Level Stock assigned to the first location. **For this research, an assumption that the depot always has a part on-hand is made. "DEPO" levels are set to be unlimited with a 9999 input level.**
28-31	Second Location **For this research, the base names indicated in Table D.6 are input consecutively in columns 28-31, 38-41, 48-51, and 58-61,**
32-36	Second Stock Level **For this research, lean stock levels computed by the ASM are input for each of the four bases in columns 32-36, 42-46, 52-56, and 63-66.**
77-80	Day Levels Start. Day on which the stock levels on this record go into effect. Each day must be greater than or equal to the previous day on any prior stock record. **For this research, a value of "1" is input.**

SAMPLE DYNA-METRIC 6.4 INPUT FILE

```
EC28.F016C Davila-Martinez/Bollinger Data Set for DM 6.4 Simulation
1   1.0      5.0   Version 6.4                                         10        0
1048015011015360201181647916466917914194625903620072096099570912919010022368465 7
   1  20  21  22  23  24
OPT
    015  1
DEPT
DEPO                                   21.  1          0.0         0.0
BASE
BAS1                                 21.              21.                      1    0
BAS2                                 21.              21.                      1    0
BAS3                                 21.              21.                      1    0
BAS4                                 21.              21.                      1    0
TRNS
BAS1 DEPO    3.     3.       21.
BAS2 DEPO    3.     3.       21.
BAS3 DEPO    3.     3.       21.
BAS4 DEPO    3.     3.       21.
ACFT
BAS1 18.
BAS2 18.
BAS3 18.
BAS4 18.
SRTS
BAS1 2.6    6 2.1   11 1.2   14 1.1
BAS2 2.6    6 2.1   11 1.2   14 1.1
BAS3 2.6    6 2.1   11 1.2   14 1.1
BAS4 2.6    6 2.1   11 1.2   14 1.1
FLHR
BAS1 3.0
BAS2 3.0
BAS3 3.0
BAS4 3.0
TURN
BAS1 3.2   11 2.6
BAS2 3.2   11 2.6
BAS3 3.2   11 2.6
BAS4 3.2   11 2.6
LRU
1270013093077     DEPO 1 0  1  101 .00346 .00346  1.0  1.0  0.0
1270013093077    X              53.0        .01 403. 403.                   0
2840013114795     DEPO 1 0 12 1201 .00106 .00106  1.0  1.0  0.0
2840013114795    X              26.0        .26 869. 869.                   0
6605012562380     DEPO 1 0  1  101 .00541 .00541  4.0  1.0  0.0
6605012562380    X              46.0        .00 455. 455.                   0
2835011156111     DEPO 1 0  1  101 .00239 .00239  5.0  .98  0.0
2835011156111    X              24.0        .14 463. 463.                   0
4810010549843     DEPO 1 0  1  101 .00027 .00027  2.0  .88  0.0
4810010549843    X             395.0        .00 319. 319.                   0
1680011689396     DEPO 1 0  1  101 .00064 .00064  4.0  1.0  0.0
1680011689396    X              93.0        .00 404. 404.                   0
5826010124864     DEPO 1 0  1  101 .00028 .00028  5.0  1.0  0.0
5826010124864    X             245.0        .00 383. 383.                   0
6115012465622     DEPO 1 0  1  101 .00162 .00162  3.0  1.0  0.0
6115012465622    X              25.0        .07 364. 364.                   0
1660013452115     DEPO 1 0  1  101 .00049 .00049  5.0  1.0  0.0
```

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1660013452115   X              112.0       .00  55.  55.                      0
1270012383662    DEPO 1 0  1  101 .00491 .00491  6.0  .80  0.0
1270012383662   X               24.0       .00 700. 700.                      0
6340011538696    DEPO 1 0  1  101 .00026 .00026  5.0  1.0  0.0
6340011538696   X              194.0       .00 400. 400.                      0
5895011126380    DEPO 1 0  1  101 .00268 .00268  6.0  1.0  0.0
5895011126380   X               28.0       .00 562. 562.                      0
6130012099062    DEPO 1 0  2  201 .00052 .00052  4.0  1.0  0.0
6130012099062   X               25.0       .09 512. 512.                      0
1290013223711    DEPO 1 0  1  101 .00226 .00226  6.0  .63  0.0
1290013223711   X                0.0       .00  11.  30.                      0
5985011469283    DEPO 1 0  1  101 .00090 .00090  6.0  1.0  0.0
5985011469283   X               53.0       .00  95.  95.                      0
6625011938861    DEPO 1 0  4  401 .00099 .00099  1.0  1.0  0.0
6625011938861   X               38.0       .00 352. 352.                      0
6610011150131    DEPO 1 0  1  101 .00093 .00093  4.0  .93  0.0
6610011150131   X               22.0       .04 629. 629.                      0
1650011657203    DEPO 1 0  4  401 .00037 .00037  6.0  1.0  0.0
1650011657203   X               35.0       .021318.1318.                      0
5985012122950    DEPO 1 0  1  101 .00186 .00186  6.0  .55  0.0
5985012122950   X               28.0       .01 621. 621.                      0
4320000620511    DEPO 1 0  2  201 .00090 .00090  6.0  1.0  0.0
4320000620511   X               21.0       .04 369. 369.                      0
5865013249103    DEPO 1 0  1  101 .00652 .00652  6.0  1.0  0.0
5865013249103   X                0.0       .00   8.0 30.                      0
4810010996392    DEPO 1 0  1  101 .00050 .00050  4.0  0.0  0.0
4810010996392   X               28.0       .09 860. 860.                      0
6620012788027    DEPO 1 0  1  101 .00042 .00042  6.0  1.0  0.0
6620012788027   X               50.0       .02 287. 287.                      0
1650012289276    DEPO 1 0  1  101 .00050 .00050  6.0  1.0  0.0
1650012289276   X               44.0       .00 429. 429.                      0
1660013632742    DEPO 1 0  1  101 .00058 .00058  2.0  1.0  0.0
1660013632742   X              122.0       .00  55.  55.                      0
```

APPL

1270013093077	BAS1	1.	BAS2	1.	BAS3	1.	BAS4	1.
2840013114795	BAS1	1.	BAS2	1.	BAS3	1.	BAS4	1.
6605012562380	BAS1	1.	BAS2	1.	BAS3	1.	BAS4	1.
2835011156111	BAS1	1.	BAS2	1.	BAS3	1.	BAS4	1.
4810010549843	BAS1	1.	BAS2	1.	BAS3	1.	BAS4	1.
1680011689396	BAS1	1.	BAS2	1.	BAS3	1.	BAS4	1.
5826010124864	BAS1	1.	BAS2	1.	BAS3	1.	BAS4	1.
6115012465622	BAS1	1.	BAS2	1.	BAS3	1.	BAS4	1.
1660013452115	BAS1	1.	BAS2	1.	BAS3	1.	BAS4	1.
1270012383662	BAS1	1.	BAS2	1.	BAS3	1.	BAS4	1.
6340011538696	BAS1	1.	BAS2	1.	BAS3	1.	BAS4	1.
5895011126380	BAS1	1.	BAS2	1.	BAS3	1.	BAS4	1.
6130012099062	BAS1	1.	BAS2	1.	BAS3	1.	BAS4	1.
1290013223711	BAS1	1.	BAS2	1.	BAS3	1.	BAS4	1.
5985011469283	BAS1	1.	BAS2	1.	BAS3	1.	BAS4	1.
6625011938861	BAS1	1.	BAS2	1.	BAS3	1.	BAS4	1.
6610011150131	BAS1	1.	BAS2	1.	BAS3	1.	BAS4	1.
1650011657203	BAS1	1.	BAS2	1.	BAS3	1.	BAS4	1.
5985012122950	BAS1	1.	BAS2	1.	BAS3	1.	BAS4	1.
4320000620511	BAS1	1.	BAS2	1.	BAS3	1.	BAS4	1.
5865013249103	BAS1	1.	BAS2	1.	BAS3	1.	BAS4	1.
4810010996392	BAS1	1.	BAS2	1.	BAS3	1.	BAS4	1.
6620012788027	BAS1	1.	BAS2	1.	BAS3	1.	BAS4	1.
1650012289276	BAS1	1.	BAS2	1.	BAS3	1.	BAS4	1.
1660013632742	BAS1	1.	BAS2	1.	BAS3	1.	BAS4	1.

VTM

1270013093077	1.0	1.0	1.0
2840013114795	1.0	1.0	1.0
6605012562380	1.0	1.0	1.0
2835011156111	1.0	1.0	1.0
4810010549843	1.0	1.0	1.0
1680011689396	1.0	1.0	1.0
5826010124864	1.0	1.0	1.0
6115012465622	1.0	1.0	1.0
1660013452115	1.0	1.0	1.0
1270012383662	1.0	1.0	1.0
6340011538696	1.0	1.0	1.0
5895011126380	1.0	1.0	1.0
6130012099062	1.0	1.0	1.0
1290013223711	1.0	1.0	1.0
5985011469283	1.0	1.0	1.0
6625011938861	1.0	1.0	1.0
6610011150131	1.0	1.0	1.0
1650011657203	1.0	1.0	1.0
5985012122950	1.0	1.0	1.0
4320000620511	1.0	1.0	1.0
5865013249103	1.0	1.0	1.0
4810010996392	1.0	1.0	1.0
6620012788027	1.0	1.0	1.0
1650012289276	1.0	1.0	1.0
1660013632742	1.0	1.0	1.0

STK

```
1270013093077    DEPO 9999 BAS1    3 BAS2    6 BAS3    3 BAS4    4    1
2840013114795    DEPO 9999 BAS1   31 BAS2   27 BAS3   37 BAS4   27    1
6605012562380    DEPO 9999 BAS1    0 BAS2    0 BAS3    1 BAS4    2    1
2835011156111    DEPO 9999 BAS1    6 BAS2    5 BAS3    9 BAS4    5    1
4810010549843    DEPO 9999 BAS1    2 BAS2    2 BAS3    2 BAS4    2    1
1680011689396    DEPO 9999 BAS1    2 BAS2    2 BAS3    4 BAS4    2    1
5826010124864    DEPO 9999 BAS1    2 BAS2    2 BAS3    2 BAS4    2    1
6115012465622    DEPO 9999 BAS1    4 BAS2    4 BAS3    5 BAS4    3    1
1660013452115    DEPO 9999 BAS1    3 BAS2    3 BAS3    3 BAS4    3    1
1270012383662    DEPO 9999 BAS1    1 BAS2    0 BAS3    0 BAS4    0    1
6340011538696    DEPO 9999 BAS1    2 BAS2    2 BAS3    2 BAS4    2    1
5895011126380    DEPO 9999 BAS1    4 BAS2    5 BAS3    7 BAS4    4    1
6130012099062    DEPO 9999 BAS1    4 BAS2    3 BAS3    4 BAS4    3    1
1290013223711    DEPO 9999 BAS1    3 BAS2    2 BAS3    0 BAS4    0    1
5985011469283    DEPO 9999 BAS1    3 BAS2    3 BAS3    4 BAS4    3    1
6625011938861    DEPO 9999 BAS1    8 BAS2    9 BAS3   10 BAS4    8    1
6610011150131    DEPO 9999 BAS1    3 BAS2    3 BAS3    4 BAS4    3    1
1650011657203    DEPO 9999 BAS1    4 BAS2    4 BAS3    3 BAS4    4    1
5985012122950    DEPO 9999 BAS1    2 BAS2    3 BAS3    1 BAS4    2    1
4320000620511    DEPO 9999 BAS1    5 BAS2    5 BAS3    6 BAS4    5    1
5865013249103    DEPO 9999 BAS1    0 BAS2    0 BAS3   13 BAS4    8    1
4810010996392    DEPO 9999 BAS1    0 BAS2    0 BAS3    0 BAS4    0    1
6620012788027    DEPO 9999 BAS1    3 BAS2    4 BAS3    3 BAS4    3    1
1650012289276    DEPO 9999 BAS1    3 BAS2    3 BAS3    1 BAS4    2    1
1660013632742    DEPO 9999 BAS1    3 BAS2    3 BAS3    2 BAS4    2    1
END
```

SAMPLE DYNA-METRIC 6.4 OUTPUT REPORT - PIPELINE REPORT

Detailed Pipeline Report (Option 15)

Key:

Deploy	- Queues for repair may be lost upon deployment. The parts essentially enter a pipeline from which there is no exit.
Retro	- Parts in the retrograde pipeline to the location.
Admin	- Parts in the administrative pipeline.
Queue	- Parts queued for repair.
In Work	- Parts in repair.
AWP	- LRUs waiting for SRUs.
Forward	- Parts in forward transportation to the location.
BOed	- Parts requisitioned from the higher echelon that have yet to be shipped.
Total	- Total pipeline.
Variance	- Variance of the total pipeline. (Not given for CIRFs at this time.)
Backorders	- Expected backorders.

Day	Part name	Loc.	Deploy	Retro	Admin	Queue	In Work	AWP	Forward	BOed	Total	Var.	BOs
20	1270013093077	DEPO	0.00	23.90	0.00	0.00	0.00	0.00	0.00	0.00	23.90	29.69	0.00
20	1270013093077	BAS1	0.00	0.00	0.50	0.00	0.00	0.00	6.20	0.00	6.70	12.41	3.80
20	1270013093077	BAS2	0.00	0.00	0.30	0.00	0.00	0.00	5.80	0.00	6.10	4.49	0.80
20	1270013093077	BAS3	0.00	0.00	0.10	0.00	0.00	0.00	6.00	0.00	6.10	4.69	3.10
20	1270013093077	BAS4	0.00	0.00	0.10	0.00	0.00	0.00	5.90	0.00	6.00	5.60	2.20
20	2840013114795	DEPO	0.00	93.50	0.00	0.00	0.00	0.00	0.00	0.00	93.50	17.65	0.00
20	2840013114795	BAS1	0.00	0.00	0.70	0.00	0.00	0.00	23.30	0.00	24.00	7.80	0.00
20	2840013114795	BAS2	0.00	0.00	0.40	0.00	0.00	0.00	18.80	0.00	19.20	28.76	0.40
20	2840013114795	BAS3	0.00	0.00	0.50	0.00	0.00	0.00	26.70	0.00	27.20	23.16	0.00
20	2840013114795	BAS4	0.00	0.00	0.60	0.00	0.00	0.00	24.70	0.00	25.30	18.01	0.90
20	6605012562380	DEPO	0.00	39.20	0.00	0.00	0.00	0.00	0.00	0.00	39.20	41.96	0.00
20	6605012562380	BAS1	0.00	0.00	0.10	0.00	0.00	0.00	10.30	0.00	10.40	11.24	10.40
20	6605012562380	BAS2	0.00	0.00	0.70	0.00	0.00	0.00	9.50	0.00	10.20	12.16	10.20
20	6605012562380	BAS3	0.00	0.00	0.00	0.00	0.00	0.00	9.80	0.00	9.80	14.56	8.80
20	6605012562380	BAS4	0.00	0.00	0.40	0.00	0.00	0.00	9.60	0.00	10.00	12.40	8.00
20	2835011156111	DEPO	0.00	17.40	0.00	0.00	0.00	0.00	0.00	0.00	17.40	28.24	0.00
20	2835011156111	BAS1	0.00	0.00	0.40	0.00	0.10	0.00	3.70	0.00	4.20	1.56	0.00
20	2835011156111	BAS2	0.00	0.00	0.10	0.00	0.00	0.00	5.10	0.00	5.20	6.76	1.10
20	2835011156111	BAS3	0.00	0.00	0.10	0.00	0.30	0.00	4.60	0.00	5.00	5.80	0.10
20	2835011156111	BAS4	0.00	0.00	0.00	0.00	0.00	0.00	4.00	0.00	4.00	2.00	0.20
20	4810010549843	DEPO	0.00	1.90	0.00	0.00	0.00	0.00	0.00	0.00	1.90	1.69	0.00

20	4810010549843	BAS1	0.00	0.00	0.00	0.00	0.10	0.00	0.70	0.00	0.80	0.36	0.00
20	4810010549843	BAS2	0.00	0.00	0.00	0.00	0.20	0.00	0.30	0.00	0.50	0.45	0.00
20	4810010549843	BAS3	0.00	0.00	0.00	0.00	0.20	0.00	0.50	0.00	0.70	1.01	0.10
20	4810010549843	BAS4	0.00	0.00	0.00	0.00	0.00	0.00	0.40	0.00	0.40	0.24	0.00
20	1680011689396	DEPO	0.00	4.60	0.00	0.00	0.00	0.00	0.00	0.00	4.60	2.64	0.00
20	1680011689396	BAS1	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	1.00	0.80	0.10
20	1680011689396	BAS2	0.00	0.00	0.10	0.00	0.00	0.00	0.70	0.00	0.80	0.36	0.00
20	1680011689396	BAS3	0.00	0.00	0.00	0.00	0.00	0.00	1.50	0.00	1.50	1.85	0.00
20	1680011689396	BAS4	0.00	0.00	0.10	0.00	0.00	0.00	1.40	0.00	1.50	1.45	0.30
20	5826010124864	DEPO	0.00	1.60	0.00	0.00	0.00	0.00	0.00	0.00	1.60	0.84	0.00
20	5826010124864	BAS1	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.00	0.20	0.16	0.00
20	5826010124864	BAS2	0.00	0.00	0.00	0.00	0.00	0.00	0.40	0.00	0.40	0.24	0.00
20	5826010124864	BAS3	0.00	0.00	0.00	0.00	0.00	0.00	0.40	0.00	0.40	0.24	0.00
20	5826010124864	BAS4	0.00	0.00	0.00	0.00	0.00	0.00	0.60	0.00	0.60	0.44	0.00
20	6115012465622	DEPO	0.00	10.90	0.00	0.00	0.00	0.00	0.00	0.00	10.90	11.09	0.00
20	6115012465622	BAS1	0.00	0.00	0.10	0.00	0.00	0.00	2.80	0.00	2.90	2.09	0.10
20	6115012465622	BAS2	0.00	0.00	0.00	0.00	0.00	0.00	3.10	0.00	3.10	1.69	0.20
20	6115012465622	BAS3	0.00	0.00	0.00	0.00	0.00	0.00	2.30	0.00	2.30	2.81	0.00
20	6115012465622	BAS4	0.00	0.00	0.30	0.00	0.00	0.00	2.70	0.00	3.00	1.40	0.40
20	1660013452115	DEPO	0.00	3.20	0.00	0.00	0.00	0.00	0.00	0.00	3.20	1.96	0.00
20	1660013452115	BAS1	0.00	0.00	0.00	0.00	0.00	0.00	0.80	0.00	0.80	0.96	0.00
20	1660013452115	BAS2	0.00	0.00	0.00	0.00	0.00	0.00	1.10	0.00	1.10	1.09	0.00
20	1660013452115	BAS3	0.00	0.00	0.00	0.00	0.00	0.00	0.50	0.00	0.50	0.25	0.00
20	1660013452115	BAS4	0.00	0.00	0.00	0.00	0.00	0.00	0.80	0.00	0.80	1.36	0.00
20	1270012383662	DEPO	0.00	29.20	0.00	0.00	0.00	0.00	0.00	0.00	29.20	27.16	0.00
20	1270012383662	BAS1	0.00	0.00	0.50	0.00	2.30	0.00	7.70	0.00	10.50	2.85	9.50
20	1270012383662	BAS2	0.00	0.00	0.20	0.00	1.90	0.00	8.50	0.00	10.60	4.84	10.60
20	1270012383662	BAS3	0.00	0.00	0.30	0.00	1.70	0.00	7.50	0.00	9.50	11.65	9.50
20	1270012383662	BAS4	0.00	0.00	0.30	0.00	1.60	0.00	5.50	0.00	7.40	10.44	7.40
20	6340011538696	DEPO	0.00	2.00	0.00	0.00	0.00	0.00	0.00	0.00	2.00	2.00	0.00
20	6340011538696	BAS1	0.00	0.00	0.00	0.00	0.00	0.00	0.40	0.00	0.40	0.24	0.00
20	6340011538696	BAS2	0.00	0.00	0.00	0.00	0.00	0.00	0.80	0.00	0.80	1.16	0.10
20	6340011538696	BAS3	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.00	0.30	0.21	0.00
20	6340011538696	BAS4	0.00	0.00	0.00	0.00	0.00	0.00	0.50	0.00	0.50	0.25	0.00
20	5895011126380	DEPO	0.00	17.90	0.00	0.00	0.00	0.00	0.00	0.00	17.90	23.09	0.00
20	5895011126380	BAS1	0.00	0.00	0.20	0.00	0.00	0.00	5.90	0.00	6.10	6.29	2.30
20	5895011126380	BAS2	0.00	0.00	0.30	0.00	0.00	0.00	4.70	0.00	5.00	6.80	1.10
20	5895011126380	BAS3	0.00	0.00	0.10	0.00	0.00	0.00	4.00	0.00	4.10	3.09	0.00
20	5895011126380	BAS4	0.00	0.00	0.00	0.00	0.00	0.00	3.30	0.00	3.30	1.21	0.10
20	6130012099062	DEPO	0.00	6.60	0.00	0.00	0.00	0.00	0.00	0.00	6.60	7.44	0.00

20	6130012099062	BAS1	0.00	0.00	0.00	0.00	0.00	0.00	1.50	0.00	1.50	1.05	0.00
20	6130012099062	BAS2	0.00	0.00	0.10	0.00	0.00	0.00	1.80	0.00	1.90	2.29	0.30
20	6130012099062	BAS3	0.00	0.00	0.20	0.00	0.00	0.00	2.00	0.00	2.20	0.96	0.00
20	6130012099062	BAS4	0.00	0.00	0.10	0.00	0.00	0.00	1.30	0.00	1.40	1.04	0.00
20	1290013223711	DEPO	0.00	11.60	0.00	0.00	0.00	0.00	0.00	0.00	11.60	9.64	0.00
20	1290013223711	BAS1	0.00	0.00	0.10	0.00	2.60	0.00	3.20	0.00	5.90	6.89	3.00
20	1290013223711	BAS2	0.00	0.00	0.40	0.00	1.90	0.00	3.40	0.00	5.70	9.61	3.70
20	1290013223711	BAS3	0.00	0.00	0.30	0.00	1.40	0.00	2.40	0.00	4.10	3.29	4.10
20	1290013223711	BAS4	0.00	0.00	0.00	0.00	1.60	0.00	2.60	0.00	4.20	7.76	4.20
20	5985011469283	DEPO	0.00	5.70	0.00	0.00	0.00	0.00	0.00	0.00	5.70	5.01	0.00
20	5985011469283	BAS1	0.00	0.00	0.00	0.00	0.00	0.00	1.60	0.00	1.60	2.64	0.30
20	5985011469283	BAS2	0.00	0.00	0.10	0.00	0.00	0.00	1.20	0.00	1.30	1.81	0.20
20	5985011469283	BAS3	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	1.00	0.80	0.00
20	5985011469283	BAS4	0.00	0.00	0.20	0.00	0.00	0.00	1.90	0.00	2.10	1.49	0.10
20	6625011938861	DEPO	0.00	27.90	0.00	0.00	0.00	0.00	0.00	0.00	27.90	31.29	0.00
20	6625011938861	BAS1	0.00	0.00	0.30	0.00	0.00	0.00	7.10	0.00	7.40	6.44	0.80
20	6625011938861	BAS2	0.00	0.00	0.00	0.00	0.00	0.00	6.50	0.00	6.50	6.05	0.20
20	6625011938861	BAS3	0.00	0.00	0.50	0.00	0.00	0.00	7.20	0.00	7.70	4.01	0.00
20	6625011938861	BAS4	0.00	0.00	0.10	0.00	0.00	0.00	7.10	0.00	7.20	10.16	1.00
20	6610011150131	DEPO	0.00	6.20	0.00	0.00	0.00	0.00	0.00	0.00	6.20	1.96	0.00
20	6610011150131	BAS1	0.00	0.00	0.00	0.00	0.00	0.00	2.10	0.00	2.10	2.49	0.30
20	6610011150131	BAS2	0.00	0.00	0.00	0.00	0.00	0.00	1.40	0.00	1.40	1.04	0.00
20	6610011150131	BAS3	0.00	0.00	0.00	0.00	0.10	0.00	1.00	0.00	1.10	1.29	0.00
20	6610011150131	BAS4	0.00	0.00	0.20	0.00	0.10	0.00	1.70	0.00	2.00	1.00	0.10
20	1650011657203	DEPO	0.00	9.30	0.00	0.00	0.00	0.00	0.00	0.00	9.30	10.81	0.00
20	1650011657203	BAS1	0.00	0.00	0.00	0.00	0.00	0.00	2.40	0.00	2.40	0.64	0.00
20	1650011657203	BAS2	0.00	0.00	0.00	0.00	0.00	0.00	2.30	0.00	2.30	1.81	0.00
20	1650011657203	BAS3	0.00	0.00	0.20	0.00	0.00	0.00	2.20	0.00	2.40	3.24	0.50
20	1650011657203	BAS4	0.00	0.00	0.20	0.00	0.00	0.00	2.40	0.00	2.60	3.04	0.20
20	5985012122950	DEPO	0.00	7.80	0.00	0.00	0.00	0.00	0.00	0.00	7.80	5.56	0.00
20	5985012122950	BAS1	0.00	0.00	0.10	0.00	1.30	0.00	2.00	0.00	3.40	1.84	1.40
20	5985012122950	BAS2	0.00	0.00	0.10	0.00	2.00	0.00	2.30	0.00	4.40	4.04	1.70
20	5985012122950	BAS3	0.00	0.00	0.10	0.00	2.10	0.00	1.90	0.00	4.10	4.89	3.10
20	5985012122950	BAS4	0.00	0.00	0.10	0.00	1.50	0.00	1.60	0.00	3.20	3.16	1.50
20	4320000620511	DEPO	0.00	14.80	0.00	0.00	0.00	0.00	0.00	0.00	14.80	9.16	0.00
20	4320000620511	BAS1	0.00	0.00	0.20	0.00	0.00	0.00	3.80	0.00	4.00	2.00	0.10
20	4320000620511	BAS2	0.00	0.00	0.00	0.00	0.00	0.00	4.20	0.00	4.20	4.76	0.60
20	4320000620511	BAS3	0.00	0.00	0.10	0.00	0.00	0.00	3.20	0.00	3.30	1.21	0.00
20	4320000620511	BAS4	0.00	0.00	0.30	0.00	0.00	0.00	3.60	0.00	3.90	2.69	0.10

Appendix E: Data Run Summary

TABLE E.1

DATA RUN SUMMARY: OBSERVED WEIGHT AND CUBIC FEET REQUIREMENTS (FLYING HOURS = 1.5, RST = 3.0)

Trial	Day 20		Day 21		Day 22		Day 23	
	Weight	Cubic Feet	Weight	Cubic Feet	Weight	Cubic Feet	Weight	Cubic Feet
1	9,799.490	976.976	5,971.830	607.751	4,708.000	469.556	4,350.000	427.064
2	10,428.820	1,059.659	7,577.490	755.661	6,197.490	619.466	5,102.160	501.178
3	10,379.650	1,055.690	7,962.650	802.872	6,047.320	617.515	4,386.490	449.951
4	10,856.990	1,087.348	8,726.490	885.093	6,457.160	676.232	4,858.160	502.937
5	11,536.500	1,214.434	8,149.000	882.546	6,529.500	671.788	5,275.000	563.728
6	12,596.330	1,338.798	9,095.000	1,156.933	7,588.500	810.562	5,358.000	564.153
7	10,149.980	1,055.213	7,561.650	783.076	6,242.990	649.572	4,698.490	495.190
8	11,552.830	1,261.120	8,930.830	991.749	7,262.330	819.560	5,746.330	626.475
9	10,039.980	1,095.202	7,792.650	838.692	5,824.650	629.040	5,150.150	549.952
10	11,313.990	1,188.956	8,120.000	873.403	6,594.500	705.461	4,863.500	525.824
11	9,253.820	904.337	7,479.820	728.746	5,836.820	578.235	4,554.660	462.046
12	10,100.660	1,106.480	7,800.160	842.742	6,367.160	656.556	4,757.160	486.964
13	10,351.660	1,175.618	7,142.660	802.257	5,268.500	588.331	4,105.500	436.214
14	11,322.160	1,135.864	8,181.990	834.065	5,972.830	617.658	4,658.830	507.512
15	9,400.820	972.980	6,530.320	656.103	4,772.150	475.274	4,217.990	418.648
16	8,190.500	830.211	6,147.000	636.737	5,647.500	562.315	4,390.000	442.327
17	8,278.820	872.450	6,382.660	673.256	5,178.330	562.322	3,569.830	406.327
18	9,738.320	1,059.332	7,863.990	856.690	6,826.330	736.792	4,990.830	552.295
19	10,612.500	1,143.745	6,831.000	749.411	5,382.500	565.515	3,656.000	408.503
20	11,206.490	1,156.215	7,484.160	769.403	5,733.330	588.150	4,226.830	452.726
AVG	10,355.516	1,084.531	7,586.568	806.359	6,021.895	629.995	4,645.796	489.001
ST DEV	1,094.778	128.325	878.966	126.017	757.066	91.823	553.467	60.944
Variance	1,198,539.128	16,467.299	772,581.089	15,880.209	573,149.127	8,431.377	306,325.276	3,714.141
Wilk-Shapiro	0.971	0.979	0.971	0.923	0.988	0.955	0.986	0.958

Trial	Day 24		Day 25		Day 26		Day 27	
	Weight	Cubic Feet	Weight	Cubic Feet	Weight	Cubic Feet	Weight	Cubic Feet
1	2,995.000	272.488	2,461.500	231.687	2,247.000	210.056	2,111.500	178.244
2	4,032.160	393.827	3,136.160	296.100	2,925.660	275.338	2,833.490	276.838
3	3,254.660	306.389	2,718.330	267.566	2,483.330	222.384	1,839.160	172.312
4	3,822.660	386.474	2,606.500	268.362	1,543.500	176.370	1,033.000	98.323
5	3,928.000	435.433	3,107.500	326.948	2,375.000	252.468	1,672.000	207.630
6	4,488.000	467.864	3,149.000	310.704	1,972.000	195.297	1,600.000	173.019
7	3,888.830	412.615	2,552.330	259.536	2,329.830	227.211	2,288.330	241.501
8	4,910.000	548.863	3,823.000	390.555	3,115.500	341.018	2,411.500	263.481
9	3,988.150	426.995	3,093.660	311.936	2,559.660	259.067	1,734.830	175.158
10	3,920.500	402.980	2,826.500	271.100	2,110.500	208.918	1,491.000	146.287
11	2,697.500	278.352	2,281.000	239.840	1,943.000	207.985	1,935.000	200.478
12	3,629.330	367.126	3,083.830	327.414	3,513.330	357.200	3,125.000	309.020
13	3,254.000	340.113	2,601.000	281.596	2,130.000	232.766	1,432.000	150.023
14	3,237.330	348.768	2,900.830	320.491	2,768.330	303.928	1,989.000	205.159
15	3,202.490	306.258	2,751.660	269.294	1,866.160	194.419	1,408.830	146.141
16	3,330.000	339.231	2,876.000	286.928	2,754.500	278.838	1,771.000	172.433
17	2,862.000	306.729	2,844.000	291.822	2,300.500	244.615	2,584.500	260.318
18	3,787.830	405.513	2,946.830	313.121	1,898.500	230.837	1,941.000	224.123
19	3,379.000	380.757	3,670.500	360.459	3,719.500	406.147	2,522.830	256.778
20	3,640.830	395.248	2,973.660	339.798	2,440.660	271.430	2,286.160	260.890
AVG	3,612.414	376.101	2,920.190	298.263	2,449.823	254.815	2,000.507	205.908
ST DEV	542.680	67.446	370.858	39.770	555.939	59.449	523.773	54.312
Variance	294,501.707	4,549.028	137,535.624	1,581.670	309,068.561	3,534.241	274,337.671	2,949.838
Wilk-Shapiro	0.959	0.952	0.932	0.974	0.951	0.909	0.983	0.968

Trial	Day 28		Day 29		Day 30		Day 31	
	Weight	Cubic Feet	Weight	Cubic Feet	Weight	Cubic Feet	Weight	Cubic Feet
1	2,123.000	179.047	1,701.830	158.039	1,482.330	142.409	1,135.330	111.093
2	2,411.160	249.369	2,534.830	262.980	2,315.830	247.412	2,209.830	240.664
3	1,778.330	155.528	1,495.830	148.996	1,755.830	194.579	1,580.830	168.465
4	858.500	91.011	640.500	74.780	758.500	78.463	845.000	82.600
5	1,492.500	168.097	892.000	98.104	975.500	112.146	1,592.500	168.732
6	844.500	109.849	877.000	117.046	913.000	123.214	832.000	107.001
7	1,894.830	208.005	1,903.330	202.481	2,037.830	214.292	1,952.330	217.189
8	2,080.000	219.061	1,696.500	170.785	872.000	96.323	1,008.500	114.738
9	1,793.000	179.284	1,958.500	218.872	1,150.000	131.695	583.000	53.419
10	1,425.000	148.876	1,198.330	121.984	751.330	77.383	989.160	86.625
11	1,669.500	180.604	1,173.500	119.520	843.500	91.782	816.830	79.945
12	1,547.500	159.576	1,580.000	163.242	2,303.000	234.932	1,750.500	182.704
13	1,250.000	132.141	689.000	80.185	693.500	80.686	737.500	83.539
14	2,034.500	205.232	1,864.000	186.575	2,236.500	234.484	1,722.000	172.140
15	951.330	101.073	1,096.500	116.326	745.000	86.160	1,202.000	132.299
16	1,954.000	177.269	2,179.000	210.282	1,461.000	138.789	1,399.330	131.262
17	2,476.500	237.420	1,819.000	177.949	1,265.000	104.072	1,149.000	107.832
18	1,576.000	203.993	1,413.500	180.317	1,771.000	201.100	1,562.500	174.494
19	2,074.330	208.936	1,953.160	209.831	1,811.000	190.651	1,193.500	122.703
20	2,187.830	243.927	1,989.330	208.807	1,628.830	185.625	1,813.500	179.865
AVG	1,721.116	177.915	1,532.782	161.355	1,388.524	148.310	1,303.757	135.865
ST DEV	480.768	45.863	521.652	50.900	566.669	58.829	452.095	49.994
Variance	231,137.692	2,103.383	272,120.731	2,590.815	321,113.217	3,460.844	204,389.916	2,499.350
Wilk-Shapiro	0.963	0.973	0.970	0.973	0.925	0.922	0.972	0.960

Trial	Day 32		Day 33		Day 34		Day 35	
	Weight	Cubic Feet	Weight	Cubic Feet	Weight	Cubic Feet	Weight	Cubic Feet
1	1,182.500	111.266	1,296.500	120.693	1,263.330	113.030	1,200.500	105.231
2	1,740.830	206.070	1,645.330	209.676	1,316.330	174.840	1,305.500	173.268
3	1,212.660	124.406	1,380.160	139.862	1,368.330	137.893	1,307.330	121.562
4	1,413.500	140.481	1,646.500	155.404	1,782.500	186.209	1,410.000	147.304
5	1,673.500	163.705	1,180.330	103.650	1,309.330	114.023	842.330	76.175
6	1,070.500	114.793	885.500	104.913	1,037.500	113.703	981.000	100.904
7	1,558.330	183.789	1,688.500	189.431	1,488.000	174.402	1,549.000	177.089
8	1,077.500	115.580	1,142.000	134.396	864.000	100.768	650.500	85.382
9	697.000	69.131	1,227.830	117.997	1,656.330	157.420	1,621.000	154.028
10	569.330	60.029	969.500	87.948	659.000	67.492	781.500	85.061
11	548.330	49.407	1,682.830	158.558	2,151.830	194.039	1,745.330	161.624
12	1,226.000	134.255	1,169.000	132.095	1,380.830	142.868	1,431.330	166.591
13	887.500	99.042	787.000	88.653	732.000	80.925	933.830	81.674
14	2,297.500	222.742	1,681.000	166.095	1,830.000	169.012	1,983.500	174.431
15	1,682.000	179.887	1,119.000	120.924	1,253.500	139.639	1,836.500	207.567
16	1,269.160	109.944	891.160	71.252	695.660	61.311	1,109.830	115.747
17	1,379.000	136.967	1,103.000	114.063	1,187.500	119.897	1,380.500	137.260
18	1,295.500	135.776	1,425.500	163.429	1,338.500	162.777	1,415.000	160.833
19	1,430.500	160.533	1,037.500	129.887	951.000	108.643	779.000	77.885
20	1,814.500	185.755	1,561.500	145.086	1,871.000	171.962	1,005.500	110.090
AVG	1,301.282	135.178	1,275.982	132.701	1,306.824	134.543	1,263.449	130.985
ST DEV	435.590	46.959	296.869	34.629	412.660	39.413	375.641	39.980
Variance	189,738.891	2,205.186	88,131.080	1,199.173	170,288.536	1,553.418	141,106.027	1,598.399
Wilk-Shapiro	0.972	0.983	0.944	0.983	0.973	0.964	0.982	0.947

Trial	Day 36		Day 37		Day 38		Day 39	
	Weight	Cubic Feet	Weight	Cubic Feet	Weight	Cubic Feet	Weight	Cubic Feet
1	1,045.500	92.918	1,693.330	142.415	1,332.500	122.359	1,629.000	149.151
2	973.330	119.838	1,110.330	137.822	1,484.830	188.542	1,509.330	182.874
3	1,310.830	114.445	1,153.330	103.980	1,287.160	113.625	1,271.500	123.938
4	1,260.500	144.379	1,168.000	119.748	924.000	97.223	916.500	97.402
5	559.830	69.113	455.500	50.931	825.000	88.652	780.500	91.818
6	883.830	95.712	1,342.500	125.754	1,373.000	134.709	1,433.000	147.742
7	1,162.500	140.549	1,120.500	131.747	927.500	104.920	950.000	92.614
8	816.500	107.362	1,124.500	125.820	1,356.500	124.645	1,170.500	100.699
9	1,658.000	171.583	1,619.500	174.123	1,279.000	149.090	1,310.500	146.710
10	595.000	60.032	838.000	78.943	575.500	70.858	873.000	104.893
11	966.500	102.174	618.000	67.279	773.330	79.073	761.830	91.874
12	1,391.830	166.162	967.330	113.537	944.830	108.118	1,066.830	117.832
13	1,383.330	125.066	1,334.660	124.541	1,009.830	95.057	1,349.830	127.001
14	1,579.500	147.960	1,703.500	157.544	1,203.500	119.481	1,069.500	107.183
15	1,876.500	199.819	1,411.500	147.918	1,195.000	133.733	1,041.500	116.838
16	1,494.330	160.801	1,413.500	153.514	1,367.830	144.372	1,074.830	120.897
17	1,052.500	111.904	1,363.500	151.744	910.500	97.950	719.000	71.598
18	860.000	106.064	769.500	81.313	606.000	81.376	698.500	77.075
19	1,142.000	119.202	1,290.830	131.813	1,116.660	115.675	901.330	102.138
20	830.000	97.152	993.500	119.055	925.330	118.820	1,448.330	157.631
AVG	1,142.116	122.612	1,174.566	121.977	1,070.890	114.414	1,098.766	116.395
ST DEV	351.619	35.030	336.631	31.944	266.080	27.689	280.671	28.688
Variance	123,635.956	1,227.101	113,320.237	1,020.417	70,798.756	766.707	78,776.415	823.030
Wilk-Shapiro	0.984	0.974	0.974	0.947	0.956	0.950	0.967	0.958

Trial	Day 40		Day 41		Day 42		Day 43	
	Weight	Cubic Feet	Weight	Cubic Feet	Weight	Cubic Feet	Weight	Cubic Feet
1	1,804.500	157.639	1,278.000	128.458	1,144.500	108.167	757.500	71.785
2	1,657.330	178.250	1,638.330	175.809	1,341.830	137.530	1,089.500	113.295
3	1,310.500	151.994	859.500	111.576	1,105.000	138.228	809.000	100.667
4	1,217.000	124.869	751.500	73.538	509.500	57.217	289.500	27.295
5	823.500	109.523	716.500	92.139	591.000	80.748	471.500	51.608
6	1,290.000	121.648	1,656.000	148.770	1,633.000	147.729	1,487.000	135.881
7	726.500	57.784	765.330	65.908	949.330	92.859	981.000	94.543
8	650.500	58.861	893.000	76.272	967.000	98.325	1,374.000	151.232
9	1,663.000	199.971	1,952.500	229.807	1,382.500	156.820	1,350.500	137.099
10	1,534.000	149.265	1,865.500	180.252	1,759.500	167.422	1,171.000	113.973
11	532.830	73.739	510.830	68.252	789.330	105.048	812.500	109.913
12	667.000	77.061	696.500	90.585	404.500	53.737	639.500	77.267
13	1,731.330	166.372	1,634.830	159.451	1,344.000	134.987	1,364.000	138.913
14	1,469.500	148.479	1,593.330	187.809	1,458.830	170.910	1,112.830	121.448
15	929.500	106.608	964.000	100.470	1,063.000	114.504	900.500	102.399
16	985.830	112.796	833.500	98.248	901.000	110.769	914.000	109.987
17	678.000	68.524	451.500	52.718	586.000	61.285	998.000	101.320
18	844.500	93.346	607.000	58.951	927.000	88.588	1,068.500	110.512
19	645.000	70.450	705.500	80.297	952.830	109.195	601.000	60.781
20	1,263.830	134.806	1,142.830	116.309	762.000	82.569	903.500	103.484
AVG	1,121.208	118.099	1,075.799	114.781	1,028.583	110.832	954.742	101.670
ST DEV	421.712	42.283	479.188	49.946	373.110	35.288	314.291	31.133
Variance	177,841.263	1,787.845	229,621.316	2,494.574	139,210.741	1,245.210	98,778.920	969.270
Wilk-Shapiro	0.935	0.968	0.905	0.926	0.982	0.977	0.983	0.944

Trial	Day 44		Day 45		Day 46		Day 47	
	Weight	Cubic Feet	Weight	Cubic Feet	Weight	Cubic Feet	Weight	Cubic Feet
1	489.000	46.356	642.830	63.766	632.160	62.506	699.330	80.815
2	901.000	99.228	863.500	87.788	1,238.330	135.470	1,396.830	138.998
3	678.000	77.944	1,100.500	124.563	710.500	78.734	1,483.000	134.159
4	242.500	25.079	372.000	45.503	462.500	54.855	515.500	62.774
5	417.500	43.396	476.000	51.140	236.500	27.310	621.500	67.878
6	991.000	95.716	741.500	78.935	716.000	75.145	585.000	46.580
7	1,045.000	98.773	598.000	48.930	666.000	61.034	851.330	75.627
8	771.500	82.065	911.000	85.284	1,062.000	106.988	1,133.500	120.749
9	996.500	99.539	855.000	86.147	1,082.000	121.640	921.500	100.703
10	1,315.000	128.609	857.000	99.970	446.500	50.385	708.000	66.265
11	553.500	70.096	1,273.500	132.024	1,328.500	158.307	1,102.500	165.547
12	272.500	40.449	243.000	32.774	253.000	33.314	507.330	50.164
13	1,121.500	109.928	1,153.000	104.603	892.000	86.670	685.000	63.605
14	1,044.000	118.057	958.500	111.500	1,178.500	141.250	961.830	97.721
15	1,094.830	115.015	1,088.000	130.926	1,366.000	173.537	926.000	102.961
16	623.000	73.082	442.500	52.779	564.500	62.546	430.500	42.247
17	1,312.000	121.785	1,022.000	94.270	499.500	45.725	590.500	58.395
18	1,254.000	124.517	1,144.500	106.301	1,036.000	98.089	811.500	78.082
19	1,311.330	134.182	1,384.330	142.741	988.830	100.369	757.830	74.787
20	640.000	80.507	461.000	49.639	611.000	64.411	595.000	65.866
AVG	853.683	89.216	829.383	86.479	798.516	86.914	814.174	84.696
ST DEV	347.769	32.000	322.164	32.885	346.508	41.600	288.529	33.460
Variance	120,943.450	1,023.977	103,789.921	1,081.410	120,067.799	1,730.570	83,248.958	1,119.589
Wilk-Shapiro	0.955	0.956	0.977	0.965	0.969	0.955	0.922	0.911

Trial	Day 48		Day 49	
	Weight	Cubic Feet	Weight	Cubic Feet
1	910.330	102.388	1,019.000	109.299
2	921.830	96.584	1,001.830	110.339
3	2,091.500	214.195	1,615.000	168.030
4	346.500	47.422	500.000	48.117
5	812.500	91.830	1,043.500	109.451
6	363.500	32.565	704.500	54.144
7	1,053.830	94.001	1,054.830	98.922
8	1,565.000	137.757	1,172.000	93.866
9	1,358.500	135.665	1,453.000	148.707
10	462.500	61.319	721.000	93.569
11	1,365.830	146.244	1,933.330	192.324
12	342.160	40.111	562.660	61.015
13	1,127.000	98.074	937.330	79.950
14	464.330	61.032	1,011.000	100.122
15	1,321.000	119.157	1,642.500	145.653
16	713.500	58.592	807.500	67.819
17	1,265.500	140.787	488.000	64.847
18	698.500	63.890	823.500	69.400
19	724.500	74.606	587.000	58.894
20	726.000	103.984	1,016.500	145.433
AVG	931.716	96.010	1,004.699	100.995
ST DEV	463.756	44.311	398.247	40.801
Variance	215,069.388	1,963.433	158,601.066	1,664.707
Wilk-Shapiro	0.941	0.934	0.926	0.935

TABLE E.2

DATA RUN SUMMARY: OBSERVED WEIGHT AND CUBIC FEET REQUIREMENTS (FLYING HOURS = 1.5, RST = 3.5)

Trial	Day20		Day21		Day22		Day23	
	Weight	Cubic Feet	Weight	Cubic Feet	Weight	Cubic Feet	Weight	Cubic Feet
1	9,799.490	976.976	6,949.330	704.484	4,866.830	478.769	3,543.330	362.738
2	10,428.820	1,059.659	7,940.490	805.617	6,189.160	636.108	4,643.160	507.380
3	10,379.650	1,055.690	8,181.150	819.939	6,654.820	666.874	5,418.160	555.337
4	10,856.990	1,087.348	8,859.490	900.224	6,746.330	682.280	5,374.330	530.825
5	11,536.500	1,214.434	8,533.500	924.847	6,436.500	680.489	5,451.000	579.095
6	12,596.330	1,338.798	11,330.500	1,186.971	8,467.500	874.683	7,567.500	755.038
7	10,149.980	1,055.213	7,952.650	810.351	7,201.490	733.824	5,823.990	604.004
8	11,552.830	1,261.120	9,725.330	1,074.362	8,320.500	917.452	6,635.000	734.261
9	10,039.980	1,095.202	8,122.150	885.234	6,073.990	674.525	5,425.990	613.145
10	11,313.990	1,188.956	8,727.500	939.048	6,914.500	731.093	5,627.500	607.637
11	9,253.820	904.337	7,910.820	775.295	6,005.490	581.900	4,771.490	478.056
12	10,100.660	1,106.480	7,877.660	853.123	6,828.160	718.299	5,615.660	583.467
13	10,351.660	1,175.618	7,553.660	845.911	5,728.000	653.613	4,660.000	510.368
14	11,322.160	1,135.864	8,779.990	922.217	7,362.830	757.019	6,545.830	644.823
15	9,400.820	972.980	6,801.820	686.970	5,216.820	517.971	5,091.490	499.481
16	8,190.500	830.211	6,189.000	640.027	5,464.000	554.987	4,518.000	448.653
17	8,278.820	872.450	6,708.660	718.514	5,553.660	598.216	4,406.830	464.654
18	9,738.320	1,059.332	8,171.990	890.541	7,000.660	758.515	5,579.660	591.275
19	10,612.500	1,143.745	7,173.500	786.371	5,305.500	579.055	3,789.000	430.646
20	11,206.490	1,156.215	7,791.660	794.448	5,642.830	585.853	4,925.160	487.243
AVG	10,355.516	1,084.531	8,064.043	848.225	6,398.979	669.076	5,270.654	549.406
ST DEV	1,094.778	128.325	1,139.402	128.616	984.068	110.392	950.322	97.654
Variance	1,198,539.128	16,467.299	1,298,237.950	16,541.977	968,390.761	12,186.371	903,111.264	9,536.339
Wilk-Shapiro	0.971	0.979	0.909	0.933	0.963	0.966	0.957	0.971

Trial	Day24		Day25		Day26		Day27	
	Weight	Cubic Feet	Weight	Cubic Feet	Weight	Cubic Feet	Weight	Cubic Feet
1	2,588.500	266.127	1,979.500	193.197	1,969.000	191.685	1,839.500	179.793
2	3,349.660	359.239	2,655.660	287.090	2,694.160	280.194	2,308.160	246.294
3	4,126.330	427.841	3,194.330	339.664	2,225.830	250.000	2,573.830	257.078
4	4,015.500	390.786	2,309.000	225.828	1,968.500	193.647	2,051.500	210.100
5	3,919.500	400.331	3,189.000	358.963	2,500.500	262.326	2,274.500	232.040
6	6,318.000	652.789	4,345.000	446.034	3,095.000	327.360	2,798.000	298.868
7	4,578.490	476.405	3,450.830	382.216	2,937.830	326.574	2,089.830	242.772
8	4,703.000	556.648	3,325.500	417.238	2,830.000	347.885	2,190.000	263.821
9	4,008.820	478.350	2,952.320	331.979	2,596.490	290.045	2,209.660	258.419
10	4,615.000	488.476	3,386.000	359.176	2,578.000	284.374	1,732.500	203.106
11	4,010.160	377.964	3,170.830	298.159	2,855.330	261.471	2,652.830	259.155
12	3,996.330	431.436	2,650.330	301.938	2,365.330	285.471	1,715.000	213.899
13	3,791.830	414.286	2,880.000	344.952	2,346.330	277.251	2,213.330	293.643
14	4,670.330	428.972	4,126.830	392.796	3,325.500	333.485	3,277.500	335.803
15	4,327.160	415.999	3,597.330	360.681	3,646.330	361.772	3,014.000	291.851
16	3,628.000	358.963	2,535.500	231.424	2,107.500	207.021	1,969.500	194.094
17	3,597.830	379.797	3,022.830	313.717	2,319.830	249.128	2,034.830	211.764
18	4,866.330	505.113	4,005.330	417.839	2,960.330	326.273	1,991.830	213.881
19	3,179.500	373.024	2,763.500	331.025	2,495.500	304.765	1,674.000	208.742
20	4,334.660	444.127	3,939.830	417.628	3,717.330	376.438	3,509.660	366.811
AVG	4,131.247	431.334	3,173.973	337.577	2,676.731	286.858	2,305.998	249.097
ST DEV	764.661	81.963	621.276	68.108	500.869	52.781	515.674	48.902
Variance	584,706.584	6,718.001	385,984.403	4,638.708	250,869.719	2,785.816	265,920.056	2,391.418
Wilk-Shapiro	0.910	0.920	0.987	0.965	0.960	0.973	0.913	0.934

Trial	Day28		Day29		Day30		Day31	
	Weight	Cubic Feet	Weight	Cubic Feet	Weight	Cubic Feet	Weight	Cubic Feet
1	1,808.000	158.339	2,382.000	214.980	1,911.330	177.027	1,858.330	168.456
2	2,231.330	231.155	1,855.830	216.363	1,540.500	190.515	1,750.000	193.921
3	2,603.830	246.297	2,366.830	216.992	1,949.830	172.996	2,110.830	195.617
4	1,698.500	171.454	1,437.500	151.916	1,574.500	148.114	1,064.500	96.003
5	2,025.500	210.469	1,461.500	146.874	1,144.000	121.664	811.000	92.143
6	2,757.500	290.820	2,230.500	231.623	2,217.000	232.803	2,126.500	221.572
7	1,805.830	210.594	1,733.330	168.240	1,457.500	147.097	1,350.500	144.138
8	1,271.500	157.680	1,307.500	158.693	1,009.000	118.238	1,015.000	127.886
9	2,435.830	274.517	2,053.330	219.357	1,950.330	216.784	1,439.830	169.120
10	1,408.000	180.868	958.830	111.708	1,253.830	130.961	1,028.830	94.189
11	2,433.500	237.821	1,780.830	164.360	1,838.830	174.218	1,434.830	134.408
12	2,090.000	243.248	1,850.000	215.140	2,033.000	236.696	1,371.500	157.362
13	2,060.000	271.476	2,165.500	267.770	2,264.000	282.156	1,994.000	247.141
14	3,153.500	308.859	3,023.500	293.365	2,333.500	223.860	1,645.000	167.238
15	1,841.500	188.566	1,312.000	145.555	1,425.500	154.999	1,195.500	139.219
16	1,744.500	155.360	1,881.500	191.859	2,069.000	195.623	1,671.000	155.330
17	1,886.830	189.745	1,429.830	153.708	914.830	107.535	976.330	124.921
18	2,124.330	215.692	1,647.500	179.207	1,599.500	167.036	1,969.500	193.453
19	1,757.000	214.454	2,046.160	244.060	2,049.330	253.002	1,917.000	215.596
20	3,509.160	369.662	2,962.660	336.353	2,824.830	317.060	2,283.330	242.909
AVG	2,132.307	226.354	1,894.332	201.406	1,768.007	188.419	1,550.666	164.031
ST DEV	555.572	56.046	532.427	55.587	486.944	56.487	443.829	46.696
Variance	308,659.762	3,141.206	283,478.047	3,089.969	237,114.227	3,190.754	196,983.748	2,180.534
Wilk-Shapiro	0.930	0.940	0.961	0.944	0.978	0.965	0.968	0.975

Trial	Day32		Day33		Day34		Day35	
	Weight	Cubic Feet	Weight	Cubic Feet	Weight	Cubic Feet	Weight	Cubic Feet
1	1,745.330	166.769	1,703.000	159.638	1,395.000	130.050	1,087.990	102.640
2	1,611.000	176.254	1,802.500	195.754	1,588.500	167.566	1,130.000	131.576
3	1,167.330	111.700	1,167.830	112.994	931.330	87.687	1,082.830	111.488
4	696.500	66.407	1,001.500	99.367	1,262.000	137.483	1,734.000	190.528
5	1,796.500	165.081	1,696.330	145.813	1,671.330	149.126	1,987.330	179.120
6	1,398.500	154.020	1,703.000	178.145	1,519.500	151.793	1,636.500	150.732
7	1,441.000	144.888	1,580.000	174.719	1,448.500	181.896	1,566.500	185.934
8	853.000	94.865	850.000	92.244	576.500	76.394	707.500	84.368
9	1,587.000	180.812	1,249.500	127.472	1,015.830	106.885	931.000	92.638
10	1,258.660	115.491	1,457.830	132.514	899.000	86.463	850.500	83.099
11	1,345.500	135.285	1,135.500	108.381	1,498.500	140.903	1,374.000	124.868
12	1,414.000	165.901	1,992.000	251.915	1,773.330	217.467	1,886.830	209.778
13	1,582.000	185.447	1,627.500	199.941	1,011.000	140.998	978.500	110.765
14	1,573.500	176.949	1,737.000	187.747	1,570.500	151.799	1,571.000	151.807
15	1,435.000	154.113	1,958.000	202.956	1,601.000	172.409	1,030.500	121.672
16	1,110.330	100.601	954.830	77.437	813.830	76.370	938.830	89.462
17	993.830	128.574	1,110.830	144.177	598.330	80.655	442.330	56.119
18	2,179.500	213.974	2,045.000	201.958	1,673.000	164.062	1,907.500	178.864
19	1,671.500	210.559	1,366.000	166.318	991.660	131.499	1,434.330	177.170
20	1,926.330	216.873	2,033.830	204.806	1,635.830	153.500	1,058.330	106.015
AVG	1,439.316	153.228	1,508.599	158.215	1,273.724	135.250	1,266.815	131.932
ST DEV	360.542	41.210	381.754	46.141	382.193	38.888	431.894	43.485
Variance	129,990.198	1,698.264	145,736.377	2,128.975	146,071.380	1,512.287	186,532.233	1,890.910
Wilk-Shapiro	0.984	0.977	0.956	0.973	0.916	0.946	0.964	0.960

Trial	Day36		Day37		Day38		Day39	
	Weight	Cubic Feet	Weight	Cubic Feet	Weight	Cubic Feet	Weight	Cubic Feet
1	726.160	70.772	683.160	67.267	836.500	83.239	1,396.500	134.910
2	1,003.000	123.167	1,151.500	135.775	1,145.500	144.747	1,387.830	156.503
3	1,120.660	114.364	1,344.660	139.134	1,023.330	104.683	654.830	87.083
4	1,929.500	212.105	1,157.500	138.831	1,274.500	165.184	973.000	125.349
5	1,863.330	172.615	1,786.330	162.622	1,816.830	173.880	1,046.000	114.572
6	1,508.000	132.971	1,324.330	117.528	1,038.830	93.518	710.330	64.410
7	1,382.500	171.878	1,215.000	152.162	1,382.000	145.222	1,097.500	107.600
8	500.000	57.044	995.500	107.257	1,183.500	133.370	1,407.000	139.604
9	1,018.500	98.847	1,682.000	191.090	1,694.500	182.120	1,854.000	194.184
10	898.500	95.088	1,098.500	122.253	1,466.000	148.202	1,343.500	136.486
11	938.000	101.955	977.830	103.617	972.830	103.721	879.330	76.373
12	1,897.830	210.579	1,717.500	187.319	1,551.500	177.249	1,240.000	131.909
13	699.330	79.881	575.000	58.441	862.500	80.529	1,115.830	99.682
14	1,495.500	159.685	812.000	94.415	1,131.000	118.475	977.000	95.398
15	619.000	69.309	998.500	106.467	845.500	96.378	1,040.500	117.367
16	770.830	97.454	708.500	82.932	1,088.500	111.068	1,262.000	126.825
17	609.330	79.673	533.000	66.998	794.500	104.349	648.500	83.228
18	1,402.000	131.529	1,386.500	127.746	1,226.830	117.923	1,725.330	166.019
19	1,438.830	166.478	1,357.500	149.975	1,707.000	172.337	639.000	67.746
20	1,096.830	117.991	888.500	96.362	459.330	42.062	1,076.830	99.691
AVG	1,145.882	123.169	1,119.666	120.410	1,175.049	124.913	1,123.741	116.247
ST DEV	447.094	45.954	366.281	37.664	349.230	38.137	338.108	33.676
Variance	199,893.252	2,111.737	134,161.436	1,418.598	121,961.624	1,454.424	114,316.867	1,134.087
Wilk-Shapiro	0.952	0.952	0.977	0.983	0.976	0.962	0.960	0.976

Trial	Day40		Day41		Day42		Day43	
	Weight	Cubic Feet	Weight	Cubic Feet	Weight	Cubic Feet	Weight	Cubic Feet
1	1,869.500	172.381	1,796.500	157.223	1,675.500	149.187	1,942.500	170.676
2	1,588.500	176.493	1,635.000	175.584	1,745.500	183.996	1,462.500	154.629
3	1,207.830	138.025	1,431.000	163.290	1,315.000	144.910	1,128.000	121.320
4	722.500	97.122	945.000	117.417	1,048.000	112.088	1,169.000	132.550
5	934.000	112.161	808.000	99.334	692.500	84.399	677.000	84.492
6	1,035.330	93.665	1,646.330	177.248	1,716.830	174.470	1,764.500	186.231
7	1,263.000	130.583	1,242.500	128.011	888.000	101.325	1,151.500	121.566
8	1,436.000	143.652	1,413.000	159.558	1,213.500	150.401	1,134.500	131.863
9	1,605.500	163.583	1,382.500	123.411	1,974.500	188.147	1,475.500	141.582
10	1,708.500	163.951	1,580.000	162.400	1,403.500	128.937	1,555.500	157.290
11	595.330	57.599	858.830	99.833	969.660	114.702	925.160	109.129
12	927.000	86.804	1,197.500	127.646	764.000	78.571	811.000	88.029
13	1,516.830	130.032	2,028.000	177.903	1,395.000	130.947	1,446.500	134.684
14	754.330	79.799	962.330	124.151	855.830	102.089	936.830	106.816
15	1,131.000	135.260	1,269.500	138.663	1,145.000	138.897	1,269.330	135.836
16	1,532.500	140.190	1,203.500	101.163	898.830	75.822	993.330	81.493
17	668.500	85.900	861.500	111.868	836.500	98.028	1,274.500	133.346
18	1,558.330	156.652	1,218.830	128.504	816.330	86.452	884.330	86.756
19	747.500	86.454	716.500	79.693	655.500	74.552	1,195.500	124.559
20	1,291.330	133.100	1,555.330	156.775	1,627.500	158.225	1,697.000	172.993
AVG	1,204.666	124.170	1,287.583	135.484	1,181.849	123.807	1,244.699	128.792
ST DEV	389.723	34.679	357.333	29.341	401.890	36.419	335.930	30.265
Variance	151,884.187	1,202.606	127,686.871	860.922	161,515.730	1,326.348	112,849.192	915.948
Wilk-Shapiro	0.959	0.957	0.976	0.957	0.939	0.961	0.980	0.969

Trial	Day44		Day45		Day46		Day47	
	Weight	Cubic Feet	Weight	Cubic Feet	Weight	Cubic Feet	Weight	Cubic Feet
1	1,562.500	141.351	1,545.830	142.242	1,533.830	135.059	1,851.830	161.594
2	1,070.500	111.407	904.500	101.337	1,097.830	104.187	996.330	119.481
3	1,120.500	126.929	958.500	113.500	1,501.500	159.550	1,732.500	183.220
4	868.500	98.577	683.000	83.939	734.500	100.703	940.500	114.283
5	676.000	86.205	696.000	85.147	592.500	68.254	1,168.000	122.525
6	1,668.500	165.994	1,897.500	192.133	1,625.500	172.817	1,178.500	138.387
7	1,161.500	122.850	1,028.500	101.070	1,202.830	123.204	1,190.330	113.413
8	1,460.500	178.875	1,124.500	133.247	1,327.000	137.959	817.000	99.032
9	1,730.000	170.206	1,781.500	185.262	1,386.000	151.075	1,502.830	179.907
10	1,313.000	133.849	1,210.500	116.980	1,155.000	115.241	1,122.000	117.933
11	1,033.500	106.246	906.000	100.560	1,149.500	121.549	1,610.500	157.115
12	781.500	84.982	893.000	101.078	1,062.830	120.236	1,422.160	148.446
13	1,350.500	129.416	1,361.500	131.486	1,264.500	112.539	381.500	36.252
14	626.830	69.845	1,021.330	113.505	1,327.830	136.957	1,626.160	180.092
15	1,142.330	119.284	939.330	104.067	841.330	84.188	977.330	105.972
16	875.000	69.415	863.000	66.975	930.500	80.610	895.000	80.049
17	919.500	106.138	825.500	84.295	855.000	91.770	931.000	103.198
18	1,026.830	109.365	814.330	87.329	750.330	75.146	836.830	80.987
19	1,396.000	130.055	1,737.000	160.417	1,847.330	186.133	1,919.830	188.809
20	1,114.000	119.408	965.000	112.209	690.000	72.224	1,030.000	108.822
AVG	1,144.875	119.020	1,107.816	115.839	1,143.782	117.470	1,206.507	126.976
ST DEV	314.405	30.303	364.854	33.302	341.254	33.809	399.065	40.050
Variance	98,850.624	918.290	133,118.579	1,109.021	116,454.431	1,143.075	159,253.048	1,603.971
Wilk-Shapiro	0.982	0.969	0.907	0.907	0.984	0.976	0.955	0.956

Trial	Day48		Day49	
	Weight	Cubic Feet	Weight	Cubic Feet
1	1,473.990	143.886	1,335.490	129.069
2	961.830	102.502	1,122.500	123.158
3	1,347.000	150.335	722.500	73.416
4	471.000	62.290	802.000	85.730
5	1,243.500	132.819	1,183.000	120.517
6	1,123.500	136.564	794.500	103.771
7	1,473.500	138.096	1,087.000	112.951
8	1,010.500	108.005	1,123.500	124.220
9	1,241.830	138.605	1,530.830	152.178
10	1,160.500	118.710	814.500	77.049
11	2,085.160	186.968	1,176.660	113.900
12	1,310.660	138.318	1,306.160	125.052
13	699.500	64.037	1,739.500	167.555
14	1,865.160	207.273	2,215.830	228.244
15	1,376.000	137.442	1,376.000	133.007
16	1,076.500	97.418	1,167.000	107.945
17	1,164.000	136.745	813.500	82.978
18	429.830	45.724	677.830	64.837
19	2,057.000	200.821	1,436.000	139.545
20	1,342.500	148.764	1,615.500	187.787
AVG	1,245.673	129.766	1,201.990	122.645
ST DEV	438.240	42.313	388.609	39.904
Variance	192,053.962	1,790.383	151,017.086	1,592.329
Wilk-Shapiro	0.948	0.938	0.933	0.929

TABLE E.3

DATA RUN SUMMARY: OBSERVED WEIGHT AND CUBIC FEET REQUIREMENTS (FLYING HOURS = 1.5, RST = 4.0)

Trial	Day20		Day21		Day22		Day23	
	Weight	Cubic Feet	Weight	Cubic Feet	Weight	Cubic Feet	Weight	Cubic Feet
1	9,799.490	976.976	7,182.830	724.785	5,770.500	595.115	4,257.000	467.591
2	10,428.820	1,059.659	8,232.990	836.351	7,027.990	707.668	5,884.490	619.365
3	10,379.650	1,055.690	9,062.150	908.204	7,994.990	806.053	6,324.330	628.597
4	10,856.990	1,087.348	8,994.490	910.319	7,067.830	718.181	5,729.830	586.320
5	11,536.500	1,214.434	8,911.500	952.456	6,981.000	754.881	5,260.000	578.419
6	12,596.330	1,338.798	10,630.500	1,221.624	8,972.500	954.329	7,094.000	748.940
7	10,149.980	1,055.213	8,144.650	838.878	7,486.490	766.692	6,487.660	677.118
8	11,552.830	1,261.120	9,729.330	1,075.287	8,320.330	916.398	7,560.330	813.701
9	10,039.980	1,095.202	8,178.480	891.926	6,763.990	730.639	6,034.320	667.234
10	11,313.990	1,188.956	8,797.000	946.746	7,110.500	746.331	6,374.000	642.263
11	9,253.820	904.337	8,174.820	797.139	7,438.820	717.663	5,498.490	556.412
12	10,100.660	1,106.480	8,061.660	879.941	7,449.330	799.553	6,042.330	649.473
13	10,351.660	1,175.618	8,270.660	916.802	6,700.330	736.181	5,754.330	629.830
14	11,322.160	1,135.864	8,896.990	931.379	7,681.320	804.403	6,128.990	659.983
15	9,400.820	972.980	6,962.820	699.964	5,768.650	566.921	4,787.320	468.251
16	8,190.500	830.211	6,270.000	646.803	5,549.000	561.565	4,094.500	421.262
17	8,278.820	872.450	6,940.990	744.919	6,295.490	665.897	4,952.990	512.592
18	9,738.320	1,059.332	8,488.490	929.659	7,850.660	830.149	7,077.660	730.285
19	10,612.500	1,143.745	7,787.500	851.038	6,197.000	674.858	4,657.500	499.321
20	11,206.490	1,156.215	8,246.660	840.903	6,707.160	684.934	5,817.330	594.310
AVG	10,355.516	1,084.531	8,298.226	877.256	7,056.694	736.921	5,790.870	607.563
ST DEV	1,094.778	128.325	998.324	128.693	885.627	101.488	930.135	100.332
Variance	1,198,539.128	16,467.299	996,650.734	16,561.968	784,334.311	10,299.910	865,151.208	10,066.424
Wilk-Shapiro	0.971	0.979	0.952	0.925	0.983	0.966	0.982	0.982

Trial	Day24		Day25		Day26		Day27	
	Weight	Cubic Feet	Weight	Cubic Feet	Weight	Cubic Feet	Weight	Cubic Feet
1	3,652.000	381.410	3,616.000	375.291	3,241.000	333.336	3,161.000	331.793
2	5,085.660	507.170	4,426.660	428.483	4,006.490	365.948	3,328.490	316.651
3	5,176.830	524.526	3,651.330	382.101	3,233.660	317.138	3,598.160	339.261
4	4,123.000	421.021	2,855.000	287.152	2,606.500	253.768	2,419.000	229.780
5	3,991.500	453.987	3,327.500	388.855	3,338.500	394.771	2,626.000	319.202
6	5,620.000	605.764	4,679.000	522.525	3,509.500	392.113	3,263.500	363.118
7	5,344.160	546.831	4,875.830	501.081	4,065.830	423.852	3,956.830	419.555
8	5,609.830	581.976	3,923.830	404.987	3,373.500	338.708	1,953.500	202.516
9	4,570.820	514.653	3,712.660	424.829	3,326.500	359.213	2,708.000	306.447
10	5,046.000	518.747	4,359.000	440.351	3,853.000	400.910	2,692.500	279.626
11	3,580.490	363.391	3,471.160	356.429	3,438.660	353.065	2,877.330	286.888
12	4,531.000	474.822	4,199.000	433.580	2,876.000	312.963	2,244.000	263.223
13	5,518.830	582.932	4,412.000	467.248	3,385.330	372.990	2,633.830	291.478
14	4,331.660	460.229	3,677.160	396.428	3,037.160	320.348	2,991.660	306.154
15	3,958.990	388.041	2,453.160	274.924	2,537.330	265.453	2,329.000	248.472
16	2,696.500	310.646	2,805.000	310.662	2,526.000	282.563	2,310.000	266.554
17	4,499.160	452.249	3,450.830	346.378	3,590.330	347.129	3,234.830	313.891
18	6,309.160	679.437	4,924.330	575.147	3,423.830	438.489	3,056.830	390.739
19	4,818.000	511.958	4,361.000	475.589	3,131.000	347.608	3,328.000	382.684
20	6,037.330	617.311	5,640.330	580.557	4,414.830	463.079	3,940.330	409.598
AVG	4,725.046	494.855	3,941.039	418.630	3,345.748	354.172	2,932.640	313.382
ST DEV	906.280	93.958	794.095	85.289	498.261	55.096	554.195	58.700
Variance	821,343.825	8,828.168	630,586.508	7,274.297	248,264.199	3,035.614	307,131.735	3,445.708
Wilk-Shapiro	0.985	0.990	0.981	0.982	0.963	0.989	0.979	0.985

Trial	Day28		Day29		Day30		Day31	
	Weight	Cubic Feet	Weight	Cubic Feet	Weight	Cubic Feet	Weight	Cubic Feet
1	2,857.500	304.025	2,528.330	255.247	1,297.830	138.260	1,793.330	166.898
2	2,749.990	279.170	2,320.490	251.907	2,006.330	234.149	1,717.330	208.124
3	3,181.660	288.561	2,307.830	219.598	2,079.330	214.860	2,026.830	215.652
4	2,184.000	212.640	2,131.000	214.898	1,457.000	161.400	1,023.500	114.174
5	1,887.500	224.770	1,630.000	192.357	1,731.000	195.954	1,532.000	154.054
6	2,967.500	328.338	2,385.500	257.484	1,839.000	210.898	2,163.000	232.391
7	3,435.000	357.887	2,805.000	293.300	2,056.000	221.972	1,689.500	194.762
8	1,473.500	151.320	1,667.000	178.265	1,219.500	121.006	1,421.000	133.126
9	2,017.000	233.917	1,883.500	239.479	1,776.000	210.740	1,775.000	196.876
10	2,291.830	228.766	1,864.830	187.105	1,931.830	197.291	2,143.660	222.298
11	2,675.000	275.071	2,773.830	277.077	2,215.830	235.109	1,510.830	171.430
12	2,045.500	247.320	1,695.000	198.009	1,972.500	241.865	2,517.500	289.415
13	2,613.830	312.566	2,338.330	279.156	2,154.330	235.066	1,703.330	188.665
14	2,547.330	254.524	2,807.830	286.839	2,345.330	246.765	2,364.330	244.154
15	1,903.500	211.582	1,499.500	172.180	1,842.500	211.482	1,375.500	147.326
16	2,467.500	275.465	1,984.500	202.066	2,055.000	210.986	1,789.500	179.645
17	2,897.830	289.872	3,155.330	312.099	3,004.330	300.670	2,729.330	266.363
18	3,213.500	406.754	2,964.500	375.249	3,088.330	380.669	2,828.830	351.192
19	2,861.830	320.712	2,374.330	284.537	2,016.330	246.972	1,832.500	220.165
20	3,414.830	359.490	3,195.000	331.863	2,885.500	300.508	2,098.000	217.578
AVG	2,584.307	278.138	2,315.582	250.436	2,048.690	225.831	1,901.740	205.714
ST DEV	545.574	60.491	519.161	55.291	497.784	57.153	461.747	55.414
Variance	297,651.388	3,659.115	269,527.946	3,057.094	247,788.979	3,266.468	213,209.945	3,070.705
Wilk-Shapiro	0.980	0.983	0.970	0.964	0.920	0.905	0.968	0.952

Trial	Day32		Day33		Day34		Day35	
	Weight	Cubic Feet	Weight	Cubic Feet	Weight	Cubic Feet	Weight	Cubic Feet
1	1,468.000	134.771	1,751.000	163.769	1,433.330	136.847	1,242.660	120.707
2	1,395.830	172.414	1,365.500	165.978	1,130.500	129.343	1,069.000	123.508
3	1,678.330	185.232	1,660.830	180.821	1,232.000	114.122	876.330	90.465
4	594.000	76.066	972.000	75.270	627.000	78.108	1,279.000	144.724
5	2,594.500	243.075	2,056.830	204.137	1,831.000	175.102	1,544.500	139.078
6	2,031.000	197.753	1,877.000	176.719	1,617.000	149.074	1,546.500	137.212
7	1,734.500	193.413	1,558.500	180.309	1,223.000	131.122	1,197.000	125.582
8	1,158.500	119.692	1,060.000	114.486	536.000	59.291	689.500	79.041
9	1,458.830	154.791	1,738.330	182.588	2,073.830	203.314	2,149.000	212.117
10	1,621.660	164.024	1,453.160	144.743	1,509.660	139.726	1,145.330	125.141
11	1,289.830	151.106	1,824.830	196.499	1,896.830	199.687	2,452.830	233.571
12	2,144.000	238.677	1,915.500	226.163	1,468.330	169.300	1,516.830	172.465
13	1,092.830	130.835	1,021.330	123.986	656.830	73.924	590.500	77.325
14	1,873.830	187.964	1,588.330	180.434	2,066.830	207.848	1,730.830	181.341
15	1,338.500	153.892	1,895.500	200.010	1,854.500	196.640	1,822.500	211.045
16	2,019.500	204.001	1,857.830	185.302	1,947.830	206.606	2,017.500	227.908
17	2,083.330	222.583	1,903.330	197.039	1,685.330	170.737	1,882.500	187.231
18	2,376.330	284.018	2,204.330	258.610	1,365.330	170.737	1,159.330	145.275
19	2,003.500	247.749	2,051.500	241.974	1,581.500	195.422	2,155.500	243.570
20	1,556.000	162.722	1,573.500	164.652	953.000	104.303	1,288.500	133.762
AVG	1,675.640	181.239	1,666.457	178.174	1,434.482	150.563	1,467.782	155.553
ST DEV	477.979	49.969	348.504	42.311	471.447	46.780	506.074	50.722
Variance	228,463.541	2,496.902	121,455.111	1,790.182	222,262.590	2,188.351	256,111.158	2,572.759
Wilk-Shapiro	0.982	0.984	0.934	0.948	0.954	0.941	0.983	0.955

Trial	Day36		Day37		Day38		Day39	
	Weight	Cubic Feet	Weight	Cubic Feet	Weight	Cubic Feet	Weight	Cubic Feet
1	1,205.160	114.145	1,495.160	132.011	1,785.160	154.882	1,752.830	158.010
2	1,117.000	141.682	994.330	121.855	1,319.830	156.872	1,095.830	127.348
3	951.330	103.616	906.830	102.978	1,246.330	143.140	1,789.330	199.063
4	908.500	113.535	1,354.000	164.975	1,216.000	150.586	1,396.500	169.597
5	1,547.500	157.241	1,676.500	168.192	1,120.000	107.653	1,311.500	113.980
6	1,179.500	101.843	1,136.500	93.930	1,072.500	97.253	1,500.000	153.338
7	1,682.000	183.807	1,771.000	178.081	1,857.000	181.740	2,300.000	217.788
8	816.000	81.599	1,347.000	140.007	1,515.500	151.900	1,418.500	147.953
9	1,704.000	176.087	1,364.000	153.848	1,854.500	225.467	1,942.500	235.082
10	1,480.330	154.828	1,309.000	140.134	1,301.000	137.489	1,503.500	168.050
11	1,787.330	173.211	1,172.830	105.257	1,478.160	144.585	1,305.830	129.358
12	1,595.000	189.907	1,524.000	178.046	1,076.500	136.671	1,281.000	139.827
13	688.160	89.342	1,028.990	123.160	819.990	88.721	1,354.490	143.666
14	1,127.330	116.128	1,029.330	101.795	1,457.330	133.051	1,690.500	184.767
15	1,992.500	228.868	2,038.000	242.984	2,156.000	262.350	1,988.500	219.044
16	1,977.000	213.646	1,955.000	212.024	2,011.330	215.009	2,075.330	196.791
17	1,637.500	163.580	1,399.000	146.225	1,542.000	168.014	1,259.000	141.505
18	981.000	109.780	981.500	107.400	800.500	80.725	883.500	98.429
19	1,481.330	165.010	1,586.160	178.163	1,406.660	165.998	805.990	91.650
20	1,327.000	135.843	1,546.000	158.492	1,922.830	217.401	1,166.000	129.342
AVG	1,359.274	145.685	1,380.757	147.478	1,447.956	155.975	1,491.032	158.229
ST DEV	384.885	41.560	324.092	39.014	386.560	46.940	393.514	40.252
Variance	148,136.411	1,727.227	105,035.376	1,522.057	149,428.782	2,203.323	154,853.011	1,620.258
Wilk-Shapiro	0.977	0.971	0.967	0.947	0.978	0.954	0.977	0.976

Trial	Day40		Day41		Day42		Day43	
	Weight	Cubic Feet	Weight	Cubic Feet	Weight	Cubic Feet	Weight	Cubic Feet
1	1,919.000	175.191	2,067.500	194.520	1,518.000	144.364	1,773.500	164.696
2	808.160	91.432	641.660	70.414	887.830	110.941	964.330	113.277
3	1,496.330	168.753	1,577.830	183.004	1,483.330	167.541	1,602.330	187.461
4	989.500	126.208	740.500	96.141	672.500	81.301	385.000	50.988
5	1,414.500	133.034	1,081.500	101.585	1,081.000	103.484	1,015.500	97.266
6	1,389.000	132.165	1,225.500	112.732	1,444.000	139.115	1,372.500	128.636
7	2,165.830	206.408	1,828.500	166.008	1,568.500	144.733	1,896.500	184.522
8	1,155.500	120.134	1,060.000	99.557	1,151.000	118.961	1,310.500	132.702
9	1,747.500	204.493	1,705.500	216.249	1,520.500	194.891	1,191.000	138.277
10	1,175.500	109.227	1,514.500	141.347	1,636.000	147.978	1,529.500	149.223
11	1,127.000	115.797	1,252.000	133.119	1,250.500	140.869	1,111.500	130.814
12	868.500	98.567	575.000	78.413	638.000	86.164	767.000	109.218
13	2,021.490	194.907	2,108.490	191.286	1,364.660	132.510	1,426.160	139.574
14	1,615.000	171.603	1,552.830	161.435	1,488.330	164.563	1,660.830	186.474
15	2,422.500	268.750	2,165.000	235.914	1,867.000	205.229	2,026.500	229.190
16	2,067.500	199.146	1,922.000	193.573	1,513.500	152.638	1,287.000	140.203
17	1,063.000	119.017	1,138.500	145.382	1,297.500	161.139	923.500	120.166
18	642.000	72.790	1,228.000	143.811	1,076.500	120.001	1,015.000	112.634
19	487.160	54.348	759.160	83.676	991.830	109.898	795.000	87.890
20	1,241.500	122.420	1,322.000	130.364	1,323.000	133.713	1,703.500	182.550
AVG	1,390.824	144.220	1,373.299	143.927	1,288.674	138.002	1,287.833	139.288
ST DEV	535.114	52.951	492.617	48.087	321.148	32.142	423.254	41.284
Variance	286,347.127	2,803.824	242,671.824	2,312.347	103,136.107	1,033.112	179,143.997	1,704.393
Wilk-Shapiro	0.983	0.957	0.973	0.976	0.953	0.980	0.988	0.968

Trial	Day44		Day45		Day46		Day47	
	Weight	Cubic Feet	Weight	Cubic Feet	Weight	Cubic Feet	Weight	Cubic Feet
1	2,000.500	173.008	1,386.500	131.890	877.500	93.203	979.830	111.836
2	721.500	83.013	941.500	109.318	883.830	105.327	1,047.830	125.610
3	1,004.330	124.809	1,105.830	125.861	935.830	101.768	1,506.830	172.405
4	458.500	53.290	660.500	76.808	552.000	60.471	543.000	55.022
5	1,035.500	96.774	1,182.500	113.982	1,807.000	168.827	1,795.500	167.920
6	1,596.500	154.545	1,715.000	162.686	1,961.500	179.630	1,446.500	129.281
7	1,805.500	180.374	1,200.500	119.182	831.500	72.302	966.330	96.043
8	1,555.000	174.764	1,560.500	168.085	1,706.000	181.073	1,710.500	169.502
9	1,170.000	150.399	877.500	120.147	591.500	76.741	813.500	113.070
10	1,489.000	167.821	1,528.500	173.015	1,683.500	185.317	1,480.000	160.367
11	1,292.000	158.545	1,651.500	193.408	1,799.000	192.184	1,424.000	161.286
12	677.500	79.205	861.500	98.117	1,203.500	121.366	1,345.330	139.310
13	1,149.660	111.185	1,241.830	116.577	1,560.330	148.593	1,511.330	145.528
14	1,684.830	196.611	1,684.500	194.437	1,602.000	188.245	1,503.330	173.321
15	1,485.000	190.614	1,387.500	173.004	1,649.830	211.680	1,446.830	177.052
16	966.000	118.241	756.000	88.593	978.500	103.289	964.000	95.983
17	1,157.330	119.615	1,604.660	171.321	1,288.660	146.200	1,111.660	129.074
18	1,457.500	157.363	1,163.000	135.462	1,245.000	137.101	924.500	92.162
19	1,787.500	174.784	1,650.500	165.224	1,074.000	130.430	1,257.500	157.195
20	1,804.000	202.836	1,867.000	207.110	1,952.500	220.227	1,576.000	169.466
AVG	1,314.883	143.390	1,301.341	142.211	1,309.174	141.199	1,267.715	137.072
ST DEV	422.300	42.700	355.684	37.692	452.663	48.346	330.019	34.346
Variance	178,337.116	1,823.316	126,511.460	1,420.660	204,903.492	2,337.326	108,912.326	1,179.668
Wilk-Shapiro	0.975	0.951	0.964	0.964	0.951	0.971	0.950	0.918

Trial	Day48		Day49	
	Weight	Cubic Feet	Weight	Cubic Feet
1	807.830	99.492	1,439.160	167.865
2	764.330	72.973	805.830	81.098
3	1,340.330	157.009	1,197.330	126.724
4	562.330	56.113	708.830	70.898
5	1,572.000	153.086	1,795.500	167.934
6	1,044.500	87.295	1,189.500	95.788
7	1,163.830	119.964	1,225.830	128.358
8	1,523.500	151.414	1,530.000	157.144
9	906.000	124.001	1,334.500	148.799
10	1,655.500	159.642	1,771.000	174.049
11	1,742.660	185.661	1,666.990	170.249
12	740.160	77.899	891.160	99.507
13	1,642.330	148.953	1,704.330	148.601
14	1,591.500	170.689	1,863.000	192.871
15	1,066.330	123.019	1,578.500	166.955
16	838.500	74.762	902.500	80.426
17	1,143.660	129.508	1,503.330	143.354
18	746.500	79.211	719.500	81.354
19	1,568.500	171.329	1,214.000	134.726
20	1,933.500	211.865	1,728.000	213.405
AVG	1,217.690	127.694	1,338.440	137.505
ST DEV	411.171	43.536	378.359	41.065
Variance	169,061.342	1,895.423	143,155.738	1,686.333
Wilk-Shapiro	0.945	0.966	0.945	0.955

TABLE E.4

DATA RUN SUMMARY: OBSERVED WEIGHT AND CUBIC FEET REQUIREMENTS (FLYING HOURS = 3.0, RST = 3.0)

Trial	Day 20		Day 21		Day 22		Day 23	
	Weight	Cubic Feet	Weight	Cubic Feet	Weight	Cubic Feet	Weight	Cubic Feet
1	21,721.31	2,198.63	16,194.65	1,611.10	10,630.32	1,058.46	8,252.82	836.48
2	22,141.65	2,292.29	15,588.49	1,624.54	12,548.16	1,323.20	10,898.16	1,149.68
3	22,488.80	2,300.64	14,355.47	1,505.01	11,196.48	1,186.03	8,871.65	930.36
4	20,638.31	2,071.98	13,710.65	1,435.17	10,232.66	1,086.49	7,277.16	788.55
5	22,274.49	2,380.58	16,161.49	1,744.88	11,637.83	1,224.50	9,129.00	922.26
6	21,114.15	2,266.95	15,946.32	1,776.77	12,014.49	1,337.65	9,238.49	1,022.56
7	22,144.47	2,300.99	17,942.32	1,860.26	12,982.49	1,348.51	11,333.16	1,189.85
8	21,357.15	2,321.07	14,755.15	1,643.06	9,925.15	1,120.06	7,872.15	886.99
9	20,758.47	2,192.86	16,324.48	1,702.72	13,091.32	1,354.83	9,793.32	1,035.64
10	21,189.15	2,205.73	14,907.32	1,575.04	12,426.16	1,279.53	-	936.27
11	17,924.48	1,813.79	13,254.65	1,362.71	9,885.66	1,013.94	7,322.66	758.55
12	20,204.64	2,122.76	14,064.32	1,494.44	11,577.99	1,225.15	9,086.33	964.01
13	19,917.65	2,169.72	12,890.32	1,443.16	9,177.65	1,066.96	7,256.99	836.49
14	20,637.82	2,106.45	14,969.49	1,593.45	11,403.49	1,249.88	8,696.99	944.66
15	19,927.13	2,083.88	15,322.64	1,589.48	10,659.31	1,114.12	7,841.48	814.29
16	19,065.99	1,888.26	13,813.16	1,349.47	10,297.16	1,043.86	8,161.83	859.94
17	19,001.65	1,991.42	13,204.15	1,452.04	10,906.65	1,177.14	8,591.32	909.00
18	19,071.65	2,019.38	14,430.32	1,523.43	10,911.49	1,173.73	7,639.49	819.08
19	21,892.66	2,328.87	16,472.33	1,729.31	12,543.50	1,332.30	8,705.00	941.49
20	21,860.15	2,304.94	17,841.15	1,858.63	13,584.82	1,430.24	11,031.32	1,154.86
AVG	20,766.59	2,168.06	15,107.44	1,593.73	11,381.64	1,207.33	8,786.71	935.05
ST DEV	1,293.39	154.90	1,451.33	151.39	1,212.37	122.35	1,212.91	122.89
Variance	1,672,861.80	23,993.29	2,106,352.46	22,919.29	149,838.29	14,969.89	1,471,144.73	15,102.52
Wilk-Shapiro	0.952	0.941	0.970	0.983	0.981	0.971	0.923	0.935

Trial	Day 24		Day 25		Day 26		Day 27	
	Weight	Cubic Feet	Weight	Cubic Feet	Weight	Cubic Feet	Weight	Cubic Feet
1	7,305.32	738.05	5,803.82	571.96	5,068.99	490.15	3,983.66	384.38
2	8,710.50	899.99	7,377.00	784.34	4,985.00	547.40	4,109.33	439.87
3	7,909.82	842.64	6,101.99	638.40	4,941.49	535.75	4,690.30	483.35
4	5,507.33	583.43	3,950.33	445.16	2,799.33	329.59	2,956.83	347.13
5	7,239.00	713.36	5,475.00	550.06	3,799.50	378.60	3,250.50	323.63
6	5,936.16	690.57	5,452.16	621.13	4,114.83	476.00	3,469.33	413.75
7	8,612.33	919.16	6,901.83	746.48	5,506.83	574.96	5,211.33	537.04
8	6,471.65	713.38	5,519.32	565.02	3,682.66	394.11	3,017.83	302.38
9	8,633.65	908.96	6,399.49	660.54	5,496.66	571.36	4,785.16	479.71
10	7,305.33	758.36	5,643.50	600.69	3,930.00	434.11	3,690.50	379.39
11	5,622.83	567.44	4,102.83	424.43	3,675.00	362.00	2,927.50	282.65
12	7,501.50	783.27	6,248.50	641.80	5,286.00	541.55	4,759.40	488.84
13	5,302.49	609.46	3,681.83	438.50	3,050.83	347.70	2,901.33	337.88
14	7,702.16	806.48	5,856.16	629.06	5,009.16	558.93	3,861.33	442.26
15	7,256.98	738.60	5,646.48	593.10	4,385.65	450.79	3,523.65	385.62
16	6,932.50	694.60	4,717.00	493.40	3,251.00	346.59	3,510.00	374.68
17	6,796.15	712.98	4,641.32	491.19	3,647.32	370.39	3,045.66	293.25
18	6,386.49	673.89	4,848.82	547.31	3,610.66	401.81	3,208.66	353.16
19	6,503.00	688.54	4,683.00	514.32	3,803.00	401.57	3,260.00	336.18
20	9,265.16	969.41	7,541.83	793.04	5,878.83	639.31	5,100.40	547.54
AVG	7,145.02	750.63	5,529.61	587.50	4,296.14	457.63	3,763.14	396.64
ST DEV	1,120.93	112.11	1,069.61	106.75	905.82	93.83	766.34	79.49
Variance	1,256,479.67	12,567.65	1,144,066.16	11,395.16	820,516.22	8,803.84	587,271.90	6,318.21
Wilk-Shapiro	0.983	0.967	0.984	0.976	0.954	0.945	0.913	0.962

Trial	Day 28		Day 29		Day 30		Day 31	
	Weight	Cubic Feet	Weight	Cubic Feet	Weight	Cubic Feet	Weight	Cubic Feet
1	2,862.66	286.52	2,579.16	247.36	2,543.83	257.83	2,519.83	246.75
2	3,691.33	389.61	3,322.83	359.85	2,689.33	285.38	2,341.16	258.73
3	3,839.16	399.66	3,333.66	356.99	2,949.33	325.85	2,352.50	284.55
4	2,418.00	271.43	2,056.00	236.47	1,494.50	176.05	1,767.00	180.57
5	2,354.00	254.08	2,223.50	233.74	1,834.00	198.84	2,400.00	253.21
6	3,345.83	372.45	3,510.83	390.86	3,393.33	367.47	3,314.83	332.56
7	4,419.83	458.37	3,668.00	354.04	4,014.00	395.33	3,530.00	366.00
8	2,576.33	277.18	3,211.83	329.60	2,933.33	311.76	2,033.83	190.83
9	3,265.49	309.41	3,434.33	343.51	2,601.00	261.47	2,810.50	288.36
10	3,558.33	354.44	2,361.00	250.71	2,109.00	208.34	1,990.83	191.70
11	2,998.50	302.20	2,437.50	240.15	2,662.50	265.94	2,179.33	216.67
12	4,098.00	411.66	3,321.00	368.06	2,441.50	247.31	3,019.00	330.46
13	2,871.33	328.47	2,927.33	303.13	2,405.83	262.48	2,666.66	303.73
14	4,376.83	462.05	3,979.33	415.34	3,096.83	323.04	3,379.83	332.43
15	3,048.65	328.18	2,475.82	268.93	2,641.16	277.61	2,457.83	276.04
16	2,814.00	298.11	2,698.33	293.56	2,834.83	285.27	1,974.16	213.12
17	2,711.50	253.07	2,576.00	254.90	2,546.00	237.77	1,966.50	183.89
18	2,955.66	332.93	2,883.83	337.48	2,908.16	346.17	2,724.83	311.15
19	3,240.83	336.40	2,586.33	279.73	2,220.00	251.54	2,336.00	265.95
20	4,974.33	507.88	4,612.66	435.77	3,753.00	362.44	3,203.00	301.23
AVG	3,321.03	346.71	3,009.96	315.01	2,703.57	282.39	2,548.38	266.40
ST DEV	717.78	72.37	646.79	62.71	591.63	58.30	520.85	56.04
Variance	515,211.66	5,237.46	418,337.66	3,932.35	350,029.58	3,398.28	271,279.44	3,140.52
Wilk-Shapiro	0.945	0.955	0.954	0.957	0.963	0.981	0.962	0.973

Trial	Day 32		Day 33		Day 34		Day 35	
	Weight	Cubic Feet	Weight	Cubic Feet	Weight	Cubic Feet	Weight	Cubic Feet
1	2,179.50	211.86	1,747.50	169.94	2,178.00	214.85	1,894.66	176.99
2	2,603.66	279.51	2,167.33	235.15	2,379.33	268.33	2,614.49	300.47
3	2,233.50	278.03	1,199.00	165.10	1,699.83	197.19	2,250.00	250.37
4	1,083.50	116.34	1,397.50	147.42	1,405.50	163.43	2,178.33	254.01
5	3,014.66	318.65	2,596.00	254.82	2,636.00	270.75	2,532.00	260.60
6	2,342.33	261.23	2,175.83	230.13	2,276.00	234.69	2,467.00	251.35
7	3,756.50	408.57	3,080.00	337.69	2,665.00	304.75	2,582.50	296.59
8	1,571.33	148.87	1,784.33	169.35	1,849.00	203.47	1,725.33	169.88
9	2,254.00	218.88	2,949.83	267.23	2,892.83	259.60	2,880.83	290.51
10	2,222.83	212.76	1,975.33	189.92	2,348.66	236.68	2,585.16	273.70
11	1,848.33	204.68	1,970.83	217.88	2,456.33	236.60	2,648.00	253.98
12	2,074.00	213.59	2,145.00	231.13	2,344.33	254.82	2,505.80	255.98
13	2,342.33	256.13	1,925.83	226.98	1,887.00	210.80	1,970.00	210.22
14	2,320.83	231.34	1,761.83	181.96	1,807.83	174.45	1,846.83	167.37
15	2,285.33	261.55	2,276.83	239.81	2,221.50	240.87	2,575.00	275.98
16	2,025.83	221.48	2,124.16	208.57	1,644.83	188.16	1,641.00	195.53
17	1,537.50	135.47	1,418.33	138.06	1,288.83	114.25	1,203.33	105.08
18	2,560.33	284.86	2,113.83	220.49	3,034.33	292.52	2,519.33	235.61
19	2,648.50	293.24	2,402.50	271.34	2,454.83	264.16	2,673.33	266.71
20	2,891.00	279.01	2,821.50	269.04	2,181.00	209.05	1,568.00	149.08
AVG	2,289.79	241.80	2,101.67	218.60	2,182.55	226.97	2,243.05	232.00
ST DEV	571.91	66.47	500.31	49.07	469.27	46.35	461.10	54.34
Variance	327,078.76	4,418.56	250,305.22	2,407.79	220,209.39	2,148.15	212,615.48	2,952.48
Wilk-Shapiro	0.939	0.944	0.971	0.963	0.984	0.972	0.918	0.924

Trial	Day 36		Day 37		Day 38		Day 39	
	Weight	Cubic Feet	Weight	Cubic Feet	Weight	Cubic Feet	Weight	Cubic Feet
1	1,507.33	147.21	1,464.66	138.60	2,254.16	208.40	2,875.33	266.55
2	2,279.33	253.02	2,250.33	256.16	2,268.83	249.49	2,663.83	290.69
3	1,785.99	205.08	1,602.66	182.32	1,593.83	168.49	1,431.83	164.30
4	1,912.83	222.43	2,168.33	233.75	2,450.33	233.72	2,418.33	247.04
5	2,180.50	230.46	2,407.50	238.31	1,842.00	190.55	2,072.50	211.58
6	2,350.50	218.90	1,900.83	173.31	2,665.50	262.65	1,846.50	184.98
7	2,325.50	261.11	2,278.50	256.36	2,819.50	264.12	2,159.50	235.80
8	1,661.83	184.79	1,463.33	150.50	1,383.83	143.36	1,522.83	159.15
9	2,643.33	252.73	2,228.33	253.12	2,563.33	280.43	1,902.50	201.18
10	2,408.66	250.79	3,294.16	344.40	3,252.16	359.46	3,315.33	354.31
11	2,757.00	280.76	2,612.83	270.85	2,421.33	226.93	2,031.83	205.07
12	2,339.83	229.99	2,171.33	228.85	2,680.33	271.46	2,070.83	204.57
13	1,520.16	163.12	1,510.66	167.17	1,083.99	120.09	1,283.82	131.44
14	1,861.33	168.37	2,036.83	173.49	1,870.33	186.98	2,036.16	199.57
15	2,467.50	268.56	2,514.00	256.95	2,760.00	297.80	2,219.50	249.85
16	1,567.33	177.83	2,263.83	244.96	1,908.16	215.58	1,898.33	207.41
17	1,430.83	122.41	2,306.33	230.82	2,207.83	227.05	1,877.00	213.75
18	2,192.83	207.74	1,879.33	184.47	1,809.83	188.59	2,033.33	215.13
19	2,558.00	247.90	3,069.33	319.07	2,589.83	264.86	2,457.00	256.06
20	1,488.50	125.15	1,655.66	159.90	1,404.83	145.96	1,762.83	193.97
AVG	2,061.96	210.92	2,153.94	223.17	2,191.50	225.30	2,093.96	219.62
ST DEV	431.15	47.74	496.30	55.72	563.79	58.61	481.76	49.44
Variance	185,889.33	2,279.16	246,312.92	3,104.89	317,860.05	3,435.01	232,094.40	2,444.74
Wilk-Shapiro	0.946	0.964	0.939	0.944	0.983	0.984	0.944	0.934

Trial	Day 40		Day 41		Day 42		Day 43	
	Weight	Cubic Feet	Weight	Cubic Feet	Weight	Cubic Feet	Weight	Cubic Feet
1	2,497.00	230.15	2,315.50	216.67	1,945.33	174.84	2,073.33	188.31
2	2,580.00	278.29	2,177.50	237.92	2,158.50	248.87	2,056.00	218.31
3	1,655.33	199.49	1,846.50	228.21	1,903.00	219.90	2,127.50	243.97
4	1,852.33	207.67	1,563.83	178.85	1,445.83	153.31	1,074.83	124.79
5	2,178.00	233.79	1,628.33	150.67	1,820.83	188.31	1,482.00	149.35
6	2,359.00	233.04	2,544.50	249.03	2,709.50	266.48	2,493.83	238.50
7	2,182.50	215.73	2,173.83	216.63	1,752.83	198.90	1,571.50	167.33
8	2,947.83	283.96	2,197.83	229.21	1,735.33	206.98	1,562.83	192.52
9	1,711.50	175.85	1,971.50	210.84	2,756.00	280.76	2,441.33	247.18
10	1,844.83	197.93	1,863.83	192.61	1,729.33	173.89	1,784.83	189.35
11	2,525.33	255.37	2,140.00	220.05	2,196.33	234.41	1,968.50	204.96
12	2,510.00	249.70	1,964.33	195.54	2,237.00	215.18	1,941.00	172.85
13	1,225.66	122.84	957.16	105.01	809.66	72.81	1,011.66	98.48
14	2,104.99	207.34	1,644.66	164.50	1,744.16	200.75	1,827.66	203.17
15	2,095.00	210.83	2,040.50	205.34	2,315.33	250.98	2,073.33	203.61
16	2,046.83	214.56	2,100.33	204.03	2,242.50	230.47	2,656.00	267.40
17	1,721.00	178.25	1,704.50	207.20	1,738.00	202.05	1,904.50	202.16
18	2,472.83	260.16	1,906.83	205.66	2,142.16	198.03	2,062.83	210.79
19	2,507.00	251.89	3,050.50	280.01	1,836.33	183.88	1,747.83	181.33
20	2,830.16	287.48	1,945.33	210.61	1,675.83	167.64	1,204.83	122.37
AVG	2,192.36	224.72	1,986.87	205.43	1,944.69	203.42	1,853.31	191.34
ST DEV	434.63	40.59	417.61	36.89	432.31	45.66	443.31	43.65
Variance	188,899.89	1,647.74	174,401.56	1,360.84	186,890.35	2,084.48	196,525.01	1,905.29
Wilk-Shapiro	0.973	0.964	0.921	0.914	0.925	0.924	0.971	0.973

Trial	Day 44		Day 45		Day 46		Day 47	
	Weight	Cubic Feet	Weight	Cubic Feet	Weight	Cubic Feet	Weight	Cubic Feet
1	2,485.33	251.22	1,973.16	206.64	1,754.16	182.35	1,889.99	199.64
2	2,405.33	246.37	2,343.00	238.78	2,374.33	251.82	2,428.83	269.15
3	1,650.50	197.26	2,127.50	244.26	2,415.50	278.89	2,432.00	259.62
4	1,478.83	159.92	1,440.83	148.00	1,418.83	153.59	1,569.83	154.36
5	1,432.00	139.81	1,466.00	148.58	1,662.00	159.99	2,395.00	225.29
6	2,443.50	238.66	1,817.00	192.61	1,664.00	179.52	2,012.83	223.66
7	2,411.00	245.41	2,332.50	219.31	1,874.83	186.08	1,942.33	201.35
8	2,190.33	251.37	2,450.00	273.46	2,598.50	296.35	2,250.00	245.70
9	2,195.00	225.49	2,269.50	226.06	1,700.33	165.42	2,164.33	232.07
10	1,701.66	176.32	1,846.66	197.65	2,147.83	207.06	1,709.83	175.95
11	2,264.00	232.69	2,096.50	222.94	1,912.00	197.17	1,901.00	207.83
12	2,615.33	243.61	2,085.00	189.23	2,140.50	203.46	1,971.83	198.99
13	1,192.66	123.66	1,666.83	158.71	1,847.00	176.84	2,670.50	263.96
14	1,697.16	193.56	1,525.66	180.02	1,950.33	217.88	2,070.83	243.28
15	2,783.33	255.95	1,770.33	167.01	1,785.83	178.36	1,498.83	145.56
16	3,068.00	310.57	3,013.00	281.25	2,763.00	254.46	1,869.50	172.59
17	2,096.83	217.64	1,899.83	189.03	1,701.00	176.48	1,518.00	163.67
18	2,228.83	223.10	1,904.50	193.95	2,295.50	232.05	1,688.50	177.88
19	1,781.33	190.01	2,053.99	201.04	1,877.66	186.26	1,920.16	183.66
20	1,545.83	197.07	1,706.33	199.25	1,971.33	218.60	1,800.33	211.80
AVG	2,083.34	215.98	1,989.41	203.89	1,992.72	205.13	1,985.22	207.80
ST DEV	500.95	44.40	377.85	36.75	347.66	39.75	324.89	37.03
Variance	250,951.88	1,971.35	142,771.75	1,350.34	120,867.05	1,579.71	105,552.66	1,371.34
Wilk-Shapiro	0.979	0.952	0.945	0.964	0.944	0.923	0.971	0.983

Trial	Day 48		Day 49	
	Weight	Cubic Feet	Weight	Cubic Feet
1	1,813.49	211.60	2,042.66	233.92
2	2,670.83	279.77	2,438.33	257.87
3	2,390.50	236.59	2,593.16	257.42
4	1,533.83	158.92	1,803.33	196.63
5	2,428.00	221.99	2,534.00	244.02
6	2,194.33	232.90	1,613.83	165.68
7	1,716.99	171.72	2,286.66	242.18
8	3,282.00	327.23	3,074.50	295.93
9	1,938.00	190.03	1,695.00	173.24
10	1,792.00	174.01	2,768.33	290.21
11	1,917.16	191.91	2,277.83	232.41
12	1,797.83	171.44	1,907.83	193.07
13	3,383.00	345.29	1,701.83	167.84
14	1,938.16	228.95	1,414.49	171.21
15	1,960.66	200.51	2,808.66	280.55
16	2,165.50	206.14	2,379.50	240.72
17	1,302.00	144.80	1,431.00	164.92
18	2,148.00	231.54	1,768.50	175.16
19	2,473.83	246.27	1,784.83	190.57
20	2,161.16	246.14	2,194.83	259.20
AVG	2,150.36	220.89	2,125.96	221.64
ST DEV	520.47	51.96	481.15	44.69
Variance	270,888.23	2,700.17	231,500.77	1,997.19
Wilk-Shapiro	0.914	0.930	0.972	0.929

TABLE E.5

DATA RUN SUMMARY: OBSERVED WEIGHT AND CUBIC FEET REQUIREMENTS (FLYING HOURS = 3.0, RST = 3.5)

Trial	Day 20		Day 21		Day 22		Day 23	
	Weight	Cubic Feet	Weight	Cubic Feet	Weight	Cubic Feet	Weight	Cubic Feet
1	21,721.31	2,198.63	16,921.15	1,701.52	12,057.65	1,217.20	9,958.82	1,000.27
2	22,141.65	2,292.29	16,675.99	1,726.51	14,115.66	1,484.23	11,849.33	1,240.97
3	22,488.80	2,300.64	15,239.97	1,575.73	11,690.81	1,223.96	10,434.48	1,076.99
4	20,638.31	2,071.98	14,130.15	1,468.27	10,931.82	1,155.91	7,882.99	824.08
5	22,274.49	2,380.58	16,461.99	1,783.03	12,033.16	1,295.23	9,015.16	971.86
6	21,114.15	2,266.95	16,998.82	1,873.77	13,590.99	1,510.28	10,878.16	1,175.56
7	22,144.47	2,300.99	18,328.82	1,896.70	14,810.99	1,528.25	11,393.33	1,214.90
8	21,357.15	2,321.07	15,339.15	1,712.56	10,786.49	1,244.45	8,577.99	957.94
9	20,758.47	2,192.86	16,665.48	1,732.42	13,256.32	1,367.53	10,362.49	1,089.21
10	21,189.15	2,205.73	15,440.32	1,627.08	12,729.99	1,351.28	10,054.16	1,071.31
11	17,924.48	1,813.79	13,889.65	1,425.36	10,694.82	1,076.35	9,386.99	948.44
12	20,204.64	2,122.76	15,293.65	1,618.12	12,426.65	1,297.26	10,496.16	1,098.07
13	19,917.65	2,169.72	13,887.82	1,565.73	10,988.65	1,245.48	8,233.32	919.05
14	20,637.82	2,106.45	16,173.99	1,704.98	12,266.32	1,327.47	9,811.49	1,080.37
15	19,927.13	2,083.88	16,267.97	1,675.51	12,950.65	1,337.63	10,741.32	1,064.65
16	19,065.99	1,888.26	14,423.16	1,397.63	10,455.16	1,034.40	8,434.66	851.00
17	19,001.65	1,991.42	13,620.65	1,486.98	11,105.82	1,216.97	8,981.66	971.49
18	19,071.65	2,019.38	14,946.65	1,594.36	12,120.65	1,277.47	8,371.66	906.77
19	21,892.66	2,328.87	17,023.83	1,788.63	14,074.83	1,486.79	10,859.33	1,139.02
20	21,860.15	2,304.94	18,178.15	1,891.35	15,677.32	1,632.84	12,367.15	1,303.89
AVG	20,766.59	2,168.06	15,795.37	1,662.31	12,438.24	1,315.55	9,904.53	1,045.29
ST DEV	1,293.39	154.90	1,394.26	148.14	1,465.46	153.54	1,268.19	129.65
Variance	1,672,861.80	23,993.32	1,943,948.46	21,945.57	2,147,579.66	23,574.37	1,608,298.85	16,809.16
Wilk-Shapiro	0.952	0.941	0.974	0.981	0.963	0.967	0.978	0.981

Trial	Day 24		Day 25		Day 26		Day 27	
	Weight	Cubic Feet	Weight	Cubic Feet	Weight	Cubic Feet	Weight	Cubic Feet
1	8,033.82	798.54	6,789.32	675.02	5,714.99	580.38	4,821.66	508.27
2	10,051.83	1,042.28	9,132.00	911.11	6,961.83	683.49	5,383.66	509.75
3	8,802.15	899.93	7,116.49	664.13	6,781.99	664.23	5,070.32	534.99
4	6,236.16	624.01	5,005.33	490.45	4,473.33	424.15	4,181.83	408.12
5	8,095.66	877.91	5,751.16	641.83	4,803.83	543.01	4,071.83	447.39
6	8,506.33	912.11	6,532.33	687.57	4,733.00	510.16	4,678.00	487.41
7	10,066.33	1,040.37	7,555.33	773.69	6,080.33	635.29	5,786.00	611.69
8	7,090.66	815.60	6,740.66	764.73	4,916.66	578.83	3,824.33	422.08
9	8,278.49	880.75	6,854.49	714.94	5,399.49	576.54	4,241.99	432.65
10	9,216.66	957.12	6,427.83	651.57	5,513.83	531.34	4,919.83	460.67
11	8,217.16	816.62	6,924.83	697.34	5,749.33	579.69	4,133.33	397.43
12	8,445.16	918.97	6,990.83	763.21	5,696.83	615.51	5,009.33	564.82
13	6,256.16	718.56	5,473.83	634.31	4,809.33	587.85	4,874.83	560.61
14	9,204.16	1,000.53	8,140.33	908.10	6,181.33	717.32	6,041.33	699.37
15	8,251.83	831.30	6,246.83	649.16	5,649.33	591.85	4,052.50	445.16
16	6,872.16	702.93	5,835.16	613.88	5,360.33	550.45	3,330.33	343.76
17	6,649.66	711.94	6,135.83	616.62	4,611.83	468.49	3,470.50	341.30
18	6,748.66	730.72	5,802.83	622.01	5,543.16	618.48	5,126.66	567.63
19	8,020.50	854.95	7,177.00	772.04	5,667.50	613.63	4,520.50	482.32
20	8,810.32	977.52	7,893.99	844.32	6,905.49	751.82	6,947.99	737.82
AVG	8,092.69	855.63	6,726.32	704.80	5,577.69	591.13	4,724.34	498.16
ST DEV	1,143.22	117.96	977.55	104.21	739.79	78.49	882.48	105.01
Variance	1,306,942.10	13,915.34	955,607.51	10,859.52	547,285.94	6,161.26	778,764.68	11,026.73
Wilk-Shapiro	0.956	0.982	0.971	0.943	0.982	0.951	0.982	0.962

Trial	Day 28		Day 29		Day 30		Day 31	
	Weight	Cubic Feet	Weight	Cubic Feet	Weight	Cubic Feet	Weight	Cubic Feet
1	3,740.33	387.86	3,104.83	338.38	3,052.33	304.17	2,297.33	230.09
2	4,555.16	431.18	3,865.16	379.29	3,840.66	396.38	3,561.66	365.94
3	5,056.66	507.33	4,474.83	480.11	3,925.50	412.58	3,528.00	375.25
4	2,975.50	269.29	3,089.00	281.73	3,415.00	305.10	3,084.50	285.53
5	3,552.33	393.90	3,154.83	337.68	2,928.50	295.27	2,376.50	249.15
6	4,588.50	489.08	4,621.00	484.66	3,854.00	413.39	2,985.50	334.87
7	5,285.00	531.25	4,404.00	430.36	4,483.50	448.37	3,933.50	412.12
8	3,507.50	403.92	3,552.50	412.45	3,595.00	390.94	3,797.50	402.78
9	3,488.66	370.60	3,533.16	370.70	3,298.66	323.77	3,028.83	308.03
10	3,716.16	357.09	3,528.50	337.74	3,407.50	315.88	2,431.50	239.63
11	3,232.33	316.25	2,942.33	302.16	2,403.00	241.43	1,931.00	201.09
12	3,172.83	367.51	3,016.83	343.02	2,811.83	275.91	2,706.83	287.11
13	4,804.83	568.48	3,681.33	437.84	3,471.50	408.02	3,109.00	351.99
14	4,869.50	566.00	4,865.00	559.29	4,206.00	419.72	3,360.00	353.50
15	3,873.00	435.58	2,820.83	320.59	2,565.33	273.00	2,513.66	264.12
16	2,963.00	313.73	2,634.00	299.82	2,132.33	265.96	2,086.16	247.68
17	3,528.50	352.72	2,942.50	302.22	2,481.50	257.49	2,176.50	249.01
18	4,732.66	527.15	3,712.16	416.65	3,626.66	382.87	3,829.66	397.66
19	3,886.83	437.98	3,315.16	383.72	3,322.49	390.33	3,558.16	402.35
20	6,263.16	657.89	4,751.33	511.14	3,618.66	383.39	3,422.16	372.50
AVG	4,089.62	434.24	3,600.46	386.48	3,322.00	345.20	2,985.90	316.52
ST DEV	883.36	100.86	688.71	78.22	622.72	65.22	632.86	67.94
Variance	780,330.84	10,172.06	474,321.90	6,118.82	387,773.37	4,253.53	400,507.29	4,615.94
Wilk-Shapiro	0.961	0.932	0.971	0.934	0.952	0.981	0.932	0.961

Trial	Day 32		Day 33		Day 34		Day 35	
	Weight	Cubic Feet	Weight	Cubic Feet	Weight	Cubic Feet	Weight	Cubic Feet
1	2,070.50	195.19	2,303.50	222.69	1,951.83	178.94	2,012.00	203.00
2	2,911.66	275.41	2,078.00	202.92	1,914.50	204.87	1,697.00	173.00
3	3,530.50	375.84	2,918.83	324.37	2,976.33	325.46	3,081.00	328.00
4	3,198.00	292.55	3,112.00	305.95	3,094.00	335.59	2,408.00	263.00
5	2,888.50	305.06	3,149.83	323.05	3,241.66	321.92	2,337.00	222.00
6	2,504.00	266.51	2,562.50	284.52	2,281.50	254.90	2,258.00	253.00
7	3,262.00	359.85	4,123.00	474.45	3,762.00	438.93	3,267.00	386.00
8	3,296.00	362.31	2,973.50	334.04	2,377.50	255.68	2,168.00	235.65
9	2,863.33	301.87	3,385.50	342.77	2,980.00	316.16	2,835.00	276.72
10	2,638.50	245.44	1,799.83	166.02	1,843.99	162.28	1,569.16	143.00
11	1,944.33	198.62	2,463.83	253.43	2,624.50	297.82	2,629.50	280.76
12	2,436.83	262.36	2,357.33	243.50	3,029.33	304.24	3,467.33	358.44
13	2,880.33	330.03	2,788.00	307.46	2,619.00	287.94	2,548.33	275.91
14	3,189.00	317.48	3,147.50	305.99	2,527.50	233.02	2,228.50	219.68
15	2,155.83	234.78	2,265.83	254.86	2,242.83	246.13	2,645.83	290.47
16	1,921.49	224.56	1,564.66	180.87	1,695.16	200.29	2,309.66	244.69
17	2,209.00	243.63	2,127.83	237.30	2,011.33	229.04	1,978.83	223.53
18	3,251.66	350.42	3,362.16	362.19	3,236.83	329.18	3,210.50	319.86
19	2,478.00	308.05	2,829.00	346.65	2,614.00	307.18	2,818.66	317.79
20	2,735.16	295.80	2,852.33	298.80	2,218.33	235.61	2,875.83	287.84
AVG	2,718.23	287.29	2,708.25	288.59	2,562.11	273.26	2,517.26	265.12
ST DEV	489.77	53.51	608.10	71.54	557.75	65.66	517.62	60.28
Variance	239,878.35	2,863.65	369,786.66	5,117.22	311,086.70	4,311.12	267,927.29	3,634.18
Wilk-Shapiro	0.944	0.957	0.979	0.952	0.969	0.953	0.989	0.992

Trial	Day 36		Day 37		Day 38		Day 39	
	Weight	Cubic Feet	Weight	Cubic Feet	Weight	Cubic Feet	Weight	Cubic Feet
1	1,986.16	177.82	1,449.66	134.61	1,458.33	141.38	2,363.33	212.54
2	2,194.50	243.75	1,989.66	238.14	2,231.33	259.58	2,982.83	315.99
3	3,129.16	327.52	2,860.16	291.39	2,648.16	274.45	2,652.66	284.59
4	2,390.83	254.23	2,714.83	300.71	2,388.00	269.50	2,637.50	285.68
5	3,462.33	336.07	2,795.83	300.91	2,183.50	228.88	1,756.00	195.42
6	2,301.50	242.30	1,849.50	200.60	2,454.50	280.79	2,385.50	261.00
7	3,154.00	356.33	2,977.50	330.15	3,219.00	338.21	3,485.50	352.15
8	2,438.50	263.08	2,740.83	274.14	2,416.33	238.48	3,058.33	295.50
9	2,915.50	297.11	2,575.00	247.88	3,105.50	322.46	2,938.00	317.57
10	1,950.16	181.15	1,788.16	209.59	2,754.66	306.29	2,983.66	336.60
11	2,239.50	242.66	1,957.00	210.02	1,853.50	206.58	1,336.50	158.73
12	2,912.33	309.65	2,110.33	245.68	2,072.33	234.59	2,283.83	244.24
13	2,021.66	210.81	2,443.83	244.94	2,433.66	240.11	2,622.65	261.05
14	3,034.50	297.99	3,229.00	298.23	2,939.83	268.66	2,582.33	246.42
15	2,506.83	250.75	2,384.83	243.72	2,271.33	226.11	2,361.33	258.36
16	2,394.83	258.13	3,109.50	356.22	2,843.33	307.61	2,495.33	264.51
17	1,823.83	199.92	2,081.83	223.35	2,107.33	242.08	1,750.83	201.52
18	3,064.00	313.31	2,988.00	312.78	3,275.50	329.04	3,386.50	337.22
19	2,265.49	249.43	2,762.33	308.78	2,190.33	271.96	2,114.33	245.13
20	2,532.33	263.80	2,427.16	249.83	2,016.66	231.61	1,643.33	183.29
AVG	2,535.90	263.79	2,461.75	261.08	2,443.16	260.92	2,491.01	262.88
ST DEV	470.51	50.05	495.90	52.49	472.33	46.90	573.04	54.19
Variance	221,374.70	2,505.35	245,918.40	2,755.52	223,094.70	2,199.97	328,371.40	2,936.41
Wilk-Shapiro	0.949	0.971	0.967	0.959	0.968	0.955	0.983	0.982

Trial	Day 40		Day 41		Day 42		Day 43	
	Weight	Cubic Feet	Weight	Cubic Feet	Weight	Cubic Feet	Weight	Cubic Feet
1	2,509.83	237.83	2,409.33	215.18	2,309.83	199.01	2,707.33	234.17
2	2,634.33	279.97	1,983.33	214.80	2,344.33	251.31	2,244.66	243.38
3	2,092.16	230.75	2,505.66	287.13	2,395.33	291.41	2,295.83	270.09
4	2,528.50	264.95	2,353.50	240.90	2,701.50	266.20	2,198.50	242.15
5	1,936.50	199.33	1,819.00	195.64	1,838.00	200.58	1,642.33	192.35
6	2,110.00	228.31	2,346.00	247.95	2,927.50	302.87	2,667.00	264.62
7	3,368.33	353.59	3,444.33	359.72	3,101.83	333.72	3,008.83	316.68
8	2,537.83	247.28	2,758.33	277.71	3,128.33	308.61	3,339.33	319.11
9	3,165.50	338.32	2,953.00	327.57	3,623.83	409.80	3,204.83	374.59
10	3,226.16	330.78	2,741.33	284.97	2,424.83	249.55	1,685.33	166.99
11	1,515.50	176.95	1,785.00	231.20	1,953.83	246.41	2,242.33	268.33
12	2,638.50	263.63	2,319.00	258.27	2,725.50	287.86	2,432.00	257.05
13	2,410.32	234.35	2,204.49	212.80	1,882.16	175.94	1,587.33	139.22
14	2,377.83	233.16	2,357.33	239.85	2,295.83	234.68	2,123.83	219.09
15	2,323.33	255.57	1,971.50	212.82	1,976.00	212.40	2,595.83	269.22
16	2,352.83	256.56	2,291.83	246.54	2,526.33	262.25	2,984.83	302.81
17	1,722.00	195.89	1,295.50	149.56	1,357.50	140.56	2,150.83	237.90
18	3,357.00	321.10	2,762.50	266.29	2,353.83	228.84	2,586.83	247.04
19	2,350.83	258.37	2,234.33	233.19	2,012.16	210.81	1,707.66	179.16
20	1,873.33	197.90	1,848.33	186.71	2,021.50	195.24	2,692.50	261.47
AVG	2,451.53	255.23	2,319.18	244.44	2,395.00	250.40	2,404.90	250.27
ST DEV	520.76	49.25	478.02	48.26	532.10	61.34	514.59	55.26
Variance	271,185.36	2,425.81	228,498.29	2,328.73	283,133.83	3,762.23	264,803.80	3,053.11
Wilk-Shapiro	0.952	0.939	0.961	0.964	0.963	0.958	0.969	0.963

Trial	Day 44		Day 45		Day 46		Day 47	
	Weight	Cubic Feet	Weight	Cubic Feet	Weight	Cubic Feet	Weight	Cubic Feet
1	2,575.33	258.40	2,569.33	253.28	1,741.00	177.23	1,913.83	199.08
2	2,397.83	228.72	1,737.33	181.96	2,381.66	233.20	2,534.83	258.25
3	1,928.83	229.71	2,007.00	232.90	2,689.00	299.99	2,305.50	249.58
4	2,037.50	212.87	1,686.00	178.20	1,398.00	151.73	1,640.33	174.61
5	1,255.33	137.58	1,151.16	132.11	1,796.16	180.99	2,063.00	209.41
6	2,296.83	228.60	2,099.33	213.74	2,539.16	257.06	2,288.16	227.38
7	2,874.33	290.02	2,852.00	281.25	2,854.16	287.29	2,133.33	225.34
8	2,932.83	294.61	2,487.50	262.52	2,085.50	219.84	2,497.00	257.87
9	3,276.33	373.86	2,690.33	307.41	2,239.66	255.63	1,850.16	216.43
10	1,870.83	188.73	1,665.00	183.37	1,675.50	192.23	1,957.33	222.57
11	2,557.33	277.31	2,429.00	244.94	2,434.50	231.45	2,723.33	266.19
12	2,770.50	288.65	2,005.50	243.73	2,745.50	306.06	1,847.66	226.81
13	1,401.00	121.03	2,137.00	191.97	1,838.50	178.42	2,025.50	203.85
14	2,245.33	235.26	2,982.83	310.35	3,176.50	353.40	2,787.50	307.55
15	2,754.33	283.74	2,331.33	232.66	2,826.83	307.37	2,160.83	239.75
16	3,016.83	287.67	3,365.83	316.29	2,914.33	278.69	2,693.50	250.65
17	2,211.50	246.58	2,174.33	239.12	1,870.83	202.50	1,512.83	161.04
18	2,459.83	239.07	2,451.83	250.13	2,461.33	236.41	2,878.33	271.27
19	1,643.33	169.61	2,492.66	241.24	2,503.83	246.67	2,965.33	296.60
20	2,596.00	260.90	2,571.00	247.33	2,614.00	247.71	2,512.50	240.89
AVG	2,355.10	242.65	2,294.32	237.22	2,339.30	242.19	2,264.54	235.26
ST DEV	541.04	58.66	512.45	47.51	487.43	52.75	421.15	36.76
Variance	292,719.29	3,440.86	262,602.93	2,256.70	237,583.61	2,782.67	177,365.93	1,351.22
Wilk-Shapiro	0.964	0.953	0.978	0.956	0.972	0.979	0.982	0.990

Trial	Day 48		Day 49	
	Weight	Cubic Feet	Weight	Cubic Feet
1	2,077.66	220.76	2,736.83	288.88
2	2,727.00	275.40	2,421.50	237.00
3	2,423.83	250.46	1,781.83	175.94
4	2,030.83	191.74	2,012.33	182.64
5	2,311.50	222.44	2,021.50	214.31
6	2,195.16	214.29	1,915.66	192.09
7	2,230.83	234.38	1,966.83	193.17
8	2,808.00	293.14	2,742.00	258.89
9	2,160.83	236.16	2,522.00	280.39
10	2,318.66	264.57	3,066.16	350.40
11	2,445.83	236.31	2,530.66	251.10
12	1,604.83	183.00	1,466.16	162.15
13	2,065.33	212.43	1,878.83	200.16
14	2,687.33	272.51	2,982.16	296.16
15	2,363.00	245.46	2,009.00	217.43
16	2,551.00	226.76	2,133.00	211.91
17	1,197.83	136.75	1,236.33	148.52
18	3,066.33	285.93	2,882.33	280.11
19	2,744.33	290.63	2,771.83	308.68
20	2,356.00	226.00	2,544.50	265.54
AVG	2,318.31	235.96	2,281.07	235.77
ST DEV	422.13	39.06	511.67	54.45
Variance	178,196.58	1,525.91	261,805.15	2,964.76
Wilk-Shapiro	0.929	0.954	0.963	0.981

TABLE E.6

DATA RUN SUMMARY: OBSERVED WEIGHT AND CUBIC FEET REQUIREMENTS (FLYING HOURS = 3.0, RST = 4.0)

Trial	Day 20		Day 21		Day 22		Day 23	
	Weight	Cubic Feet	Weight	Cubic Feet	Weight	Cubic Feet	Weight	Cubic Feet
1	21,721.31	2,198.63	17,503.65	1,773.91	14,459.49	1,484.08	11,848.66	1,199.19
2	22,141.65	2,292.29	17,128.32	1,786.38	15,528.99	1,620.44	12,836.82	1,331.63
3	22,488.80	2,300.64	16,403.97	1,696.36	12,817.48	1,343.14	10,892.82	1,122.05
4	20,638.31	2,071.98	14,785.15	1,537.65	11,418.82	1,188.59	9,063.82	930.47
5	22,274.49	2,380.58	16,863.99	1,820.27	13,112.99	1,402.64	10,750.66	1,149.59
6	21,114.15	2,266.95	18,062.32	1,965.94	14,820.49	1,616.02	13,030.49	1,389.03
7	22,144.47	2,300.99	18,765.15	1,946.64	15,489.98	1,618.21	12,732.48	1,338.16
8	21,357.15	2,321.07	15,689.15	1,740.50	12,060.82	1,346.00	9,428.32	1,047.94
9	20,758.47	2,192.86	16,710.98	1,739.58	13,088.65	1,388.88	10,670.66	1,128.10
10	21,189.15	2,205.73	15,940.32	1,690.64	13,301.49	1,405.64	10,583.16	1,148.75
11	17,924.48	1,813.79	14,170.65	1,447.34	11,579.32	1,174.65	9,961.32	1,018.71
12	20,204.64	2,122.76	16,560.98	1,734.63	13,365.31	1,380.83	11,899.49	1,195.01
13	19,917.65	2,169.72	14,252.82	1,608.38	12,054.32	1,357.90	10,676.99	1,181.89
14	20,637.82	2,106.45	16,682.49	1,747.90	12,883.99	1,381.27	10,688.33	1,171.04
15	19,927.13	2,083.88	16,741.47	1,718.94	13,400.31	1,380.79	11,286.65	1,123.76
16	19,065.99	1,888.26	14,968.66	1,444.74	12,272.83	1,200.78	9,880.83	956.58
17	19,001.65	1,991.42	14,801.15	1,614.54	11,945.82	1,303.76	10,532.15	1,155.15
18	19,071.65	2,019.38	15,771.15	1,672.66	12,806.65	1,357.08	10,661.32	1,114.12
19	21,892.66	2,328.87	17,743.33	1,881.51	15,305.33	1,620.02	11,507.83	1,207.13
20	21,860.15	2,304.94	18,943.65	1,962.08	16,220.82	1,696.05	14,751.32	1,506.40
AVG	20,766.59	2,168.06	16,424.47	1,726.53	13,396.70	1,413.34	11,184.21	1,170.74
ST DEV	1,293.39	154.90	1,391.86	149.64	1,432.80	151.81	1,361.17	139.48
Variance	1,672,861.80	23,993.32	1,937,264.55	22,392.49	2,052,908.20	23,046.06	1,852,774.90	19,454.81
Wilk-Shapiro	0.952	0.941	0.979	0.963	0.945	0.923	0.922	0.941

Trial	Day 24		Day 25		Day 26		Day 27	
	Weight	Cubic Feet	Weight	Cubic Feet	Weight	Cubic Feet	Weight	Cubic Feet
1	9,971.16	989.49	8,257.66	829.53	7,482.16	739.39	5,923.33	577.79
2	10,603.82	1,109.69	8,870.32	916.00	8,548.66	864.51	7,632.83	771.21
3	10,068.16	1,040.03	8,916.99	908.56	7,817.33	780.06	7,548.33	747.51
4	7,108.99	731.01	5,820.99	606.22	4,606.66	483.26	4,664.16	487.27
5	8,915.16	968.29	7,846.99	833.66	6,042.99	638.69	5,790.16	613.80
6	10,049.66	1,134.60	7,533.66	855.24	5,725.16	671.50	5,530.66	618.47
7	9,817.48	1,055.30	8,622.48	924.69	8,370.48	909.64	6,602.15	725.48
8	8,404.32	903.64	6,392.83	696.01	5,303.33	583.28	4,738.33	540.21
9	8,813.66	974.89	7,469.49	821.45	6,473.16	685.11	5,295.33	546.56
10	9,131.83	979.09	7,601.33	817.07	6,615.83	710.14	4,588.83	453.07
11	7,407.15	759.15	5,834.49	596.17	4,838.49	482.12	4,421.49	428.34
12	9,005.49	884.95	7,492.33	736.90	7,192.33	726.19	6,249.33	663.20
13	7,422.83	817.22	7,123.83	780.58	5,319.66	566.47	5,441.16	575.13
14	9,657.83	1,048.26	8,271.66	906.49	7,591.66	811.90	6,570.16	703.21
15	9,531.16	938.15	7,904.16	801.16	6,571.66	684.46	5,967.83	609.14
16	8,340.00	824.71	7,088.50	709.96	5,950.00	609.92	4,832.50	495.99
17	8,020.82	853.28	6,424.82	665.01	5,145.99	525.64	4,048.66	440.51
18	9,957.82	1,040.45	7,652.65	813.81	6,716.99	721.21	6,511.66	725.01
19	9,108.33	934.11	7,795.33	814.97	6,669.83	713.99	5,717.16	610.94
20	11,363.99	1,183.26	9,999.66	1,043.61	8,618.99	887.46	7,044.49	749.05
AVG	9,134.98	958.48	7,646.01	803.86	6,580.07	689.75	5,755.93	604.09
ST DEV	1,116.94	122.86	1,047.04	111.92	1,227.74	124.69	1,030.20	109.37
Variance	1,247,557.64	15,093.70	1,096,282.56	12,526.02	1,507,341.79	15,548.58	1,061,308.70	11,961.38
Wilk-Shapiro	0.978	0.989	0.973	0.964	0.981	0.980	0.982	0.964

Trial	Day 28		Day 29		Day 30		Day 31	
	Weight	Cubic Feet	Weight	Cubic Feet	Weight	Cubic Feet	Weight	Cubic Feet
1	4,432.80	450.76	4,479.80	445.98	4,516.80	447.59	4,099.30	392.90
2	7,069.00	725.08	5,722.00	611.80	4,778.00	501.92	3,548.30	385.18
3	6,981.50	708.67	6,284.50	601.57	4,738.50	475.03	4,531.00	444.51
4	4,418.80	463.57	3,646.80	360.79	3,689.30	352.74	2,987.30	283.03
5	4,544.20	485.21	3,561.30	383.18	2,739.80	284.55	3,500.30	387.26
6	5,185.70	584.07	4,227.70	454.30	3,341.70	353.26	3,831.20	358.98
7	6,063.50	668.04	5,506.70	588.71	5,009.20	514.56	3,700.80	404.13
8	2,997.30	324.55	4,000.30	413.90	3,526.80	366.84	2,800.80	302.00
9	4,941.80	494.30	3,975.80	391.43	3,864.80	393.32	3,639.80	381.11
10	3,140.30	317.54	3,203.20	320.52	2,620.70	274.56	2,912.30	305.23
11	4,027.00	400.19	3,425.00	348.38	3,534.50	342.94	3,411.80	333.39
12	5,413.30	543.37	4,889.80	507.85	5,146.00	505.65	5,520.50	546.87
13	4,902.20	517.94	3,851.30	410.98	3,701.80	402.91	3,500.80	367.18
14	6,068.80	629.92	5,914.30	586.72	5,250.30	517.07	5,416.00	538.77
15	4,877.70	505.48	4,010.70	434.34	3,689.70	397.36	3,746.70	380.92
16	4,066.50	430.74	3,482.30	371.60	3,094.70	330.85	3,094.20	334.21
17	4,054.30	447.61	3,527.30	384.67	3,156.30	341.70	3,353.80	355.42
18	5,664.20	616.02	4,697.20	527.37	4,635.80	506.43	5,012.80	534.09
19	4,733.70	512.86	3,965.00	446.19	3,751.50	436.38	2,999.70	352.67
20	6,029.00	623.67	5,804.20	597.27	5,277.80	508.83	4,895.80	478.87
AVG	4,980.58	522.48	4,408.76	459.38	4,003.20	412.73	3,825.16	393.34
ST DEV	1,108.01	115.40	956.71	95.37	846.27	80.66	829.45	77.90
Variance	1,227,689.97	13,316.64	915,287.49	9,096.22	716,174.83	6,505.68	687,992.21	6,069.03
Wilk-Shapiro	0.978	0.983	0.914	0.923	0.951	0.932	0.913	0.914

Trial	Day 32		Day 33		Day 34		Day 35	
	Weight	Cubic Feet	Weight	Cubic Feet	Weight	Cubic Feet	Weight	Cubic Feet
1	3,984.20	373.27	3,321.70	346.93	3,706.20	391.05	2,975.70	314.93
2	3,784.80	396.64	4,064.80	412.72	3,867.30	376.06	3,417.80	335.42
3	3,780.80	389.14	3,979.00	389.28	3,226.50	310.36	3,308.70	333.75
4	2,725.80	271.05	2,510.30	252.81	2,486.70	276.60	2,596.30	284.59
5	3,529.30	353.54	2,989.30	320.49	3,290.70	346.46	2,712.20	288.96
6	3,837.70	357.70	3,894.20	380.55	3,105.00	302.81	3,365.50	320.34
7	4,339.80	489.04	4,774.30	544.51	5,115.30	566.76	4,970.50	452.04
8	2,501.30	258.53	1,952.30	232.73	2,108.30	234.73	2,294.80	258.68
9	3,239.00	346.55	3,418.50	349.48	3,752.50	363.87	4,025.80	415.04
10	2,372.00	235.08	2,911.00	287.72	2,881.00	290.88	2,692.20	270.66
11	4,121.50	400.73	3,481.20	362.17	3,955.70	392.07	3,291.70	323.31
12	4,235.00	428.33	3,856.00	402.24	3,175.00	343.46	2,779.50	293.45
13	3,369.30	364.46	2,605.80	313.37	2,794.30	318.23	2,948.30	319.11
14	4,836.30	476.12	4,030.80	407.02	3,341.80	334.76	3,767.30	375.98
15	3,022.30	305.40	3,498.80	361.51	3,822.30	411.73	3,781.30	426.57
16	3,276.70	335.72	3,625.20	374.24	2,639.00	295.26	2,764.70	288.31
17	3,175.50	324.13	2,831.50	305.48	2,664.80	264.41	2,588.80	255.51
18	4,375.30	476.99	5,046.30	504.08	4,470.30	440.27	4,368.30	433.99
19	3,342.70	378.25	2,859.70	331.75	3,315.50	372.55	3,129.50	365.17
20	3,972.30	397.91	4,036.50	382.37	3,714.50	361.35	3,261.30	322.60
AVG	3,591.08	367.93	3,484.36	363.07	3,371.64	349.68	3,252.01	333.92
ST DEV	653.43	69.57	764.46	74.01	708.70	73.09	665.87	59.32
Variance	426,975.93	4,839.41	584,404.87	5,477.77	502,254.96	5,341.74	443,376.01	3,519.36
Wilk-Shapiro	0.989	0.977	0.967	0.963	0.964	0.912	0.933	0.932

Trial	Day 36		Day 37		Day 38		Day 39	
	Weight	Cubic Feet	Weight	Cubic Feet	Weight	Cubic Feet	Weight	Cubic Feet
1	2,615.30	278.03	2,283.80	240.12	1,974.00	205.28	2,734.50	282.03
2	3,015.20	288.79	2,797.20	274.30	3,398.80	360.95	3,709.20	390.32
3	2,378.70	224.24	2,940.20	281.68	2,427.80	249.08	2,956.30	309.44
4	2,817.30	316.65	2,906.80	350.38	2,514.80	292.34	2,499.30	271.97
5	2,627.20	278.24	2,670.70	285.13	2,335.70	241.23	2,459.70	268.43
6	2,967.50	285.85	3,026.50	291.26	2,930.30	265.61	2,192.80	206.94
7	4,899.00	452.08	4,875.00	460.30	4,125.00	473.63	3,769.50	445.61
8	2,097.70	253.85	2,529.70	260.60	2,875.20	296.99	2,971.70	297.11
9	3,665.80	378.00	3,072.80	326.21	2,697.00	287.61	3,219.50	355.01
10	3,074.20	317.41	3,822.70	380.49	4,083.80	420.18	4,142.80	427.38
11	3,378.70	333.38	3,422.30	334.92	3,601.70	354.78	3,094.70	292.10
12	2,319.00	252.08	2,094.50	227.15	1,829.50	187.32	2,171.50	192.82
13	2,836.50	298.59	3,230.30	335.70	2,750.70	276.97	2,281.80	246.95
14	3,759.50	371.04	3,830.50	372.43	3,998.00	384.09	3,843.00	399.67
15	3,333.80	381.73	2,995.00	327.18	2,519.50	256.44	2,477.00	254.48
16	3,418.20	359.16	3,110.20	321.54	2,884.00	301.80	2,376.70	226.53
17	2,212.30	224.09	2,113.80	231.39	1,569.00	187.97	1,911.00	218.01
18	3,612.80	348.42	4,122.80	394.93	3,762.30	354.64	3,198.50	300.25
19	3,221.80	364.17	3,147.50	335.95	3,345.50	362.80	2,718.50	293.98
20	3,153.80	317.54	2,770.80	278.16	2,760.20	287.42	2,680.80	301.89
AVG	3,070.22	316.17	3,088.16	315.49	2,919.14	302.36	2,870.44	299.05
ST DEV	650.67	58.44	681.04	59.28	742.61	75.90	622.87	71.81
Variance	423,373.61	3,415.15	463,816.50	3,514.23	551,468.79	5,760.80	387,961.84	5,157.21
Wilk-Shapiro	0.933	0.971	0.932	0.962	0.973	0.973	0.961	0.941

Trial	Day 40		Day 41		Day 42		Day 43	
	Weight	Cubic Feet	Weight	Cubic Feet	Weight	Cubic Feet	Weight	Cubic Feet
1	2,774.00	284.17	2,349.20	245.40	2,569.70	249.06	2,199.70	222.78
2	3,119.80	327.75	2,962.50	317.58	3,121.80	341.51	3,111.80	343.01
3	3,137.80	311.79	3,007.30	281.12	2,759.80	283.39	2,381.80	256.70
4	1,912.80	203.67	1,601.50	169.26	1,620.00	170.34	1,410.50	148.08
5	1,743.50	187.64	1,734.80	182.26	1,734.80	201.46	1,535.30	161.30
6	2,009.80	201.12	1,716.30	176.93	2,669.80	272.57	2,471.70	264.33
7	3,283.50	387.52	3,229.80	380.66	3,252.30	356.46	3,537.80	370.30
8	2,867.70	305.84	2,672.70	310.74	3,139.50	352.96	2,781.00	311.88
9	4,418.50	484.79	3,424.00	374.79	3,267.50	354.34	2,292.80	276.08
10	3,083.80	325.55	2,788.80	289.32	2,718.80	288.90	1,869.00	207.03
11	3,137.20	305.39	2,397.70	240.68	1,989.20	219.84	2,347.20	253.97
12	2,370.00	227.89	2,543.00	261.41	1,727.00	172.29	2,328.00	228.32
13	2,638.30	286.18	2,543.00	252.81	2,690.50	270.32	2,588.00	255.03
14	3,444.50	351.12	3,060.70	340.42	2,891.80	314.94	3,589.80	385.57
15	1,785.00	169.57	2,522.50	237.63	2,381.50	238.28	2,148.00	209.79
16	3,097.70	296.41	3,457.20	332.08	3,571.80	357.29	3,445.30	338.13
17	2,524.50	292.04	2,639.00	288.16	2,692.00	286.51	2,559.00	278.39
18	3,378.00	353.57	3,518.00	375.73	2,875.50	311.55	2,316.30	267.85
19	2,430.00	248.08	2,374.20	256.84	1,925.70	205.80	2,138.80	220.58
20	3,216.80	346.70	3,622.00	381.16	3,978.00	414.13	4,383.00	471.14
AVG	2,818.66	294.84	2,708.21	284.75	2,678.85	283.10	2,571.74	273.51
ST DEV	659.18	75.28	594.24	67.10	637.56	68.20	728.02	78.42
Variance	434,518.58	5,666.86	353,118.23	4,502.03	406,476.87	4,650.96	530,014.48	6,149.22
Wilk-Shapiro	0.943	0.950	0.961	0.962	0.963	0.971	0.930	0.952

Trial	Day 44		Day 45		Day 46		Day 47	
	Weight	Cubic Feet	Weight	Cubic Feet	Weight	Cubic Feet	Weight	Cubic Feet
1	2,063.00	209.42	2,741.00	280.31	1,515.70	150.34	1,806.30	183.69
2	2,299.00	256.88	2,856.00	318.98	2,496.00	279.01	2,870.80	313.61
3	2,576.50	277.34	2,880.50	316.53	3,306.50	356.35	3,552.50	393.13
4	1,542.00	159.23	1,997.50	220.06	2,365.80	283.41	2,569.00	298.35
5	1,424.80	146.54	1,507.80	149.82	1,888.30	184.60	2,752.30	257.13
6	2,602.50	270.70	2,922.50	305.72	3,372.70	359.95	2,866.30	298.06
7	2,864.50	268.91	2,944.50	280.77	2,611.80	222.99	2,693.80	240.13
8	2,712.50	318.86	2,999.00	347.25	3,065.00	352.51	2,538.00	288.73
9	2,789.30	310.24	2,873.80	317.73	2,944.80	311.99	2,908.70	289.84
10	2,650.00	307.66	2,456.50	274.14	2,549.00	270.58	2,333.70	231.90
11	2,602.80	274.81	2,132.80	226.37	3,044.30	291.04	2,642.30	260.53
12	2,671.80	269.05	2,109.30	210.32	2,562.50	242.63	2,610.50	257.01
13	2,856.20	267.52	2,825.80	266.60	3,250.30	311.11	3,195.30	315.75
14	3,198.50	324.99	3,427.00	363.19	4,554.00	484.38	3,085.70	340.06
15	2,822.50	259.98	2,990.00	278.88	3,521.00	326.46	3,708.00	348.63
16	3,729.30	349.29	3,404.00	326.76	3,175.50	295.86	2,634.50	268.42
17	2,326.50	240.21	1,814.30	178.89	2,242.20	238.55	2,544.70	278.48
18	2,630.80	271.56	2,681.80	298.81	2,315.00	257.16	2,745.50	293.30
19	2,269.70	243.03	2,961.20	287.68	2,781.20	284.08	3,324.20	360.64
20	3,942.00	412.95	3,029.50	323.97	3,131.50	330.97	3,247.00	342.02
AVG	2,628.71	271.96	2,677.74	278.64	2,834.66	291.70	2,831.46	292.97
ST DEV	594.90	59.94	513.40	56.00	657.93	71.29	435.37	49.35
Variance	353,899.72	3,592.18	263,580.25	3,136.21	432,869.32	5,081.66	189,546.81	2,435.09
Wilk-Shapiro	0.919	0.929	0.907	0.939	0.952	0.943	0.952	0.981

Trial	Day 48		Day 49	
	Weight	Cubic Feet	Weight	Cubic Feet
1	2,388.30	246.86	2,746.80	264.58
2	2,575.30	277.52	2,246.00	243.50
3	2,901.50	329.87	3,282.80	370.94
4	3,012.00	323.10	2,486.00	282.33
5	3,007.50	297.88	3,143.50	300.65
6	3,119.00	312.62	2,156.80	245.00
7	2,085.50	174.82	1,920.50	190.48
8	2,977.00	322.97	2,621.00	250.60
9	3,282.70	323.69	3,698.70	371.90
10	2,400.30	247.27	2,695.30	293.39
11	2,127.30	233.40	2,155.30	221.84
12	1,569.20	156.00	1,389.30	134.82
13	3,624.80	357.68	3,085.80	310.50
14	2,748.70	288.75	3,046.30	319.92
15	2,184.80	222.03	2,407.80	243.23
16	2,624.50	264.47	3,111.00	335.55
17	2,325.70	251.21	2,367.70	262.20
18	2,682.50	299.84	3,054.50	312.79
19	3,090.70	344.32	3,084.20	319.37
20	2,088.00	222.64	2,870.80	322.81
AVG	2,640.77	274.85	2,678.51	279.82
ST DEV	499.33	55.30	544.74	58.58
Variance	249,333.82	3,057.94	296,744.03	3,431.35
Wilk-Shapiro	0.983	0.959	0.963	0.971

Appendix F: Observed Test Statistic Summary

TABLE F.1

OBSERVED TEST STATISTIC SUMMARY FOR WEIGHT AND CUBIC FEET REQUIREMENTS (FH = 1.5, RST = 3.0)

20 Trial Runs	AVG Weight	T-Stat	Reject Ho	AVG Cubic Feet	T-Stat	Reject Ho
Day 20	10,355.516	-47.567	Yes	1,084.531	-28.419	Yes
Day 21	7,586.568	-73.335	Yes	806.359	-38.812	Yes
Day 22	6,021.895	-94.386	Yes	629.995	-61.854	Yes
Day 23	4,645.796	-140.226	Yes	489.001	-103.541	Yes
Day 24	3,612.414	-151.529	Yes	376.101	-101.044	Yes
Day 25	2,920.190	-230.081	Yes	298.263	-180.114	Yes
Day 26	2,449.823	-157.267	Yes	254.815	-123.760	Yes
Day 27	2,000.507	-170.762	Yes	205.908	-139.493	Yes
Day 28	1,721.116	-188.636	Yes	177.915	-167.923	Yes
Day 29	1,532.782	-175.466	Yes	161.355	-152.759	Yes
Day 30	1,388.524	-162.665	Yes	148.310	-133.162	Yes
Day 31	1,303.757	-204.728	Yes	135.865	-157.810	Yes
Day 32	1,301.282	-212.510	Yes	135.178	-168.071	Yes
Day 33	1,275.982	-312.194	Yes	132.701	-228.236	Yes
Day 34	1,306.824	-224.259	Yes	134.543	-200.322	Yes
Day 35	1,263.449	-246.876	Yes	130.985	-197.881	Yes
Day 36	1,142.116	-265.285	Yes	122.612	-226.912	Yes
Day 37	1,174.566	-276.666	Yes	121.977	-248.922	Yes
Day 38	1,070.890	-351.765	Yes	114.414	-288.391	Yes
Day 39	1,098.766	-333.034	Yes	116.395	-278.039	Yes
Day 40	1,121.208	-221.414	Yes	118.099	-188.466	Yes
Day 41	1,075.799	-195.280	Yes	114.781	-159.848	Yes
Day 42	1,028.583	-251.366	Yes	110.832	-226.749	Yes
Day 43	954.742	-299.459	Yes	101.670	-258.322	Yes
Day 44	853.683	-271.931	Yes	89.216	-253.068	Yes
Day 45	829.383	-293.881	Yes	86.479	-246.628	Yes
Day 46	798.516	-273.633	Yes	86.914	-194.912	Yes
Day 47	814.174	-328.376	Yes	84.696	-242.625	Yes
Day 48	931.716	-203.168	Yes	96.010	-182.071	Yes
Day 49	1,004.699	-235.768	Yes	100.995	-197.187	Yes

TABLE F.2

OBSERVED TEST STATISTIC SUMMARY FOR WEIGHT AND CUBIC FEET REQUIREMENTS (FH = 1.5, RST = 3.5)

20 Trial Runs	AVG Weight	T-Stat	Reject Ho	AVG Cubic Feet	T-Stat	Reject Ho
Day 20	10,355.516	-47.567	Yes	1,084.531	-28.419	Yes
Day 21	8,064.043	-54.698	Yes	848.225	-36.572	Yes
Day 22	6,398.979	-70.899	Yes	669.076	-49.867	Yes
Day 23	5,270.654	-78.727	Yes	549.406	-61.851	Yes
Day 24	4,131.247	-104.506	Yes	431.334	-80.134	Yes
Day 25	3,173.973	-135.515	Yes	337.577	-102.592	Yes
Day 26	2,676.731	-172.533	Yes	286.858	-136.682	Yes
Day 27	2,305.998	-170.794	Yes	249.097	-150.976	Yes
Day 28	2,132.307	-159.927	Yes	226.354	-133.546	Yes
Day 29	1,894.332	-168.878	Yes	201.406	-136.656	Yes
Day 30	1,768.007	-185.812	Yes	188.419	-135.508	Yes
Day 31	1,550.666	-206.053	Yes	164.031	-166.255	Yes
Day 32	1,439.316	-255.034	Yes	153.228	-189.561	Yes
Day 33	1,508.599	-240.051	Yes	158.215	-168.820	Yes
Day 34	1,273.724	-242.523	Yes	135.250	-202.946	Yes
Day 35	1,266.815	-214.686	Yes	131.932	-181.835	Yes
Day 36	1,145.882	-208.597	Yes	123.169	-172.918	Yes
Day 37	1,119.666	-254.940	Yes	120.410	-211.303	Yes
Day 38	1,175.049	-266.678	Yes	124.913	-208.156	Yes
Day 39	1,123.741	-276.129	Yes	116.247	-236.879	Yes
Day 40	1,204.666	-238.630	Yes	124.170	-229.010	Yes
Day 41	1,287.583	-259.222	Yes	135.484	-268.942	Yes
Day 42	1,181.849	-231.659	Yes	123.807	-218.110	Yes
Day 43	1,244.699	-276.309	Yes	128.792	-261.727	Yes
Day 44	1,144.875	-296.646	Yes	119.020	-262.836	Yes
Day 45	1,107.816	-256.082	Yes	115.839	-239.596	Yes
Day 46	1,143.782	-273.321	Yes	117.470	-235.784	Yes
Day 47	1,206.507	-233.023	Yes	126.976	-197.985	Yes
Day 48	1,245.673	-211.793	Yes	129.766	-187.100	Yes
Day 49	1,201.990	-239.345	Yes	122.645	-199.192	Yes

TABLE F.3

OBSERVED TEST STATISTIC SUMMARY FOR WEIGHT AND CUBIC FEET REQUIREMENTS (FH = 1.5, RST = 4.0)

20 Trial Runs	AVG Weight	T-Stat	Reject Ho	AVG Cubic Feet	T-Stat	Reject Ho
Day 20	10,355.516	-47.567	Yes	1,084.531	-28.419	Yes
Day 21	8,298.226	-61.379	Yes	877.256	-35.541	Yes
Day 22	7,056.694	-75.459	Yes	736.921	-51.252	Yes
Day 23	5,790.870	-77.934	Yes	607.563	-57.609	Yes
Day 24	4,725.046	-85.245	Yes	494.855	-66.881	Yes
Day 25	3,941.039	-101.703	Yes	418.630	-77.675	Yes
Day 26	3,345.748	-167.431	Yes	354.172	-125.474	Yes
Day 27	2,932.640	-153.866	Yes	313.382	-120.878	Yes
Day 28	2,584.307	-159.153	Yes	278.138	-119.906	Yes
Day 29	2,315.582	-169.565	Yes	250.436	-133.423	Yes
Day 30	2,048.690	-179.244	Yes	225.831	-131.001	Yes
Day 31	1,901.740	-194.657	Yes	205.714	-136.736	Yes
Day 32	1,675.640	-190.162	Yes	181.239	-153.826	Yes
Day 33	1,666.457	-260.928	Yes	178.174	-181.993	Yes
Day 34	1,434.482	-195.084	Yes	150.563	-167.246	Yes
Day 35	1,467.782	-181.441	Yes	155.553	-153.806	Yes
Day 36	1,359.274	-239.833	Yes	145.685	-188.777	Yes
Day 37	1,380.757	-284.525	Yes	147.478	-200.892	Yes
Day 38	1,447.956	-237.768	Yes	155.975	-166.161	Yes
Day 39	1,491.032	-233.077	Yes	158.229	-193.515	Yes
Day 40	1,390.824	-172.238	Yes	144.220	-148.289	Yes
Day 41	1,373.299	-187.256	Yes	143.927	-163.317	Yes
Day 42	1,288.674	-288.415	Yes	138.002	-245.158	Yes
Day 43	1,287.833	-218.846	Yes	139.288	-190.730	Yes
Day 44	1,314.883	-219.054	Yes	143.390	-183.975	Yes
Day 45	1,301.341	-260.251	Yes	142.211	-208.563	Yes
Day 46	1,309.174	-204.418	Yes	141.199	-162.694	Yes
Day 47	1,267.715	-280.947	Yes	137.072	-229.546	Yes
Day 48	1,217.690	-226.041	Yes	127.694	-182.054	Yes
Day 49	1,338.440	-244.216	Yes	137.505	-191.942	Yes

TABLE F.4

OBSERVED TEST STATISTIC SUMMARY FOR WEIGHT AND CUBIC FEET REQUIREMENTS (FH = 3.0, RST = 3.0)

20 Trial Runs	AVG Weight	T-Stat	Reject Ho	AVG Cubic Feet	T-Stat	Reject Ho
Day 20	20,766.59	-4.26	Yes	2,168.06	7.74	No
Day 21	15,107.44	-21.24	Yes	1,593.73	-9.05	Yes
Day 22	11,381.64	-39.17	Yes	1,207.33	-25.32	Yes
Day 23	8,786.71	-48.72	Yes	935.05	-35.12	Yes
Day 24	7,145.02	-59.27	Yes	750.63	-45.85	Yes
Day 25	5,529.61	-68.86	Yes	587.50	-54.99	Yes
Day 26	4,296.14	-87.41	Yes	457.63	-68.75	Yes
Day 27	3,763.14	-106.43	Yes	396.63	-84.58	Yes
Day 28	3,321.03	-116.38	Yes	346.71	-95.99	Yes
Day 29	3,009.96	-131.30	Yes	315.01	-113.04	Yes
Day 30	2,703.57	-145.86	Yes	282.39	-124.10	Yes
Day 31	2,548.38	-167.02	Yes	266.40	-130.37	Yes
Day 32	2,289.79	-154.13	Yes	241.80	-111.56	Yes
Day 33	2,101.67	-177.87	Yes	218.60	-153.24	Yes
Day 34	2,182.55	-188.86	Yes	226.97	-161.43	Yes
Day 35	2,243.05	-191.62	Yes	232.00	-137.28	Yes
Day 36	2,061.96	-206.81	Yes	210.92	-158.23	Yes
Day 37	2,153.94	-178.83	Yes	223.17	-134.58	Yes
Day 38	2,191.50	-157.13	Yes	225.30	-127.79	Yes
Day 39	2,093.96	-184.79	Yes	219.62	-151.99	Yes
Day 40	2,192.36	-203.81	Yes	224.72	-184.57	Yes
Day 41	1,986.87	-214.32	Yes	205.43	-205.43	Yes
Day 42	1,944.69	-207.47	Yes	203.42	-166.18	Yes
Day 43	1,853.31	-203.24	Yes	191.34	-175.06	Yes
Day 44	2,083.34	-177.80	Yes	215.98	-169.62	Yes
Day 45	1,989.41	-236.84	Yes	203.89	-206.42	Yes
Day 46	1,992.72	-257.37	Yes	205.13	-190.71	Yes
Day 47	1,985.22	-275.51	Yes	207.80	-204.36	Yes
Day 48	2,150.36	-170.56	Yes	220.89	-144.51	Yes
Day 49	2,125.96	-184.73	Yes	221.64	-167.96	Yes

TABLE F.5

OBSERVED TEST STATISTIC SUMMARY FOR WEIGHT AND CUBIC FEET REQUIREMENTS (FH = 3.0, RST = 3.5)

20 Trial Runs	AVG Weight	T-Stat	Reject Ho	AVG Cubic Feet	T-Stat	Reject Ho
Day 20	20,766.59	-4.26	Yes	2,168.06	7.74	No
Day 21	15,795.37	-19.90	Yes	1,662.31	-7.18	Yes
Day 22	12,438.24	-29.18	Yes	1,315.55	-17.02	Yes
Day 23	9,904.53	-42.65	Yes	1,045.29	-29.48	Yes
Day 24	8,092.69	-54.40	Yes	855.63	-39.59	Yes
Day 25	6,726.32	-69.87	Yes	704.80	-51.29	Yes
Day 26	5,577.69	-99.28	Yes	591.13	-74.57	Yes
Day 27	4,724.34	-87.55	Yes	498.16	-59.70	Yes
Day 28	4,089.62	-90.67	Yes	434.24	-64.99	Yes
Day 29	3,600.46	-119.48	Yes	386.48	-86.53	Yes
Day 30	3,322.00	-134.14	Yes	345.20	-106.61	Yes
Day 31	2,985.90	-134.37	Yes	316.52	-104.23	Yes
Day 32	2,718.23	-176.06	Yes	287.29	-134.78	Yes
Day 33	2,708.25	-141.88	Yes	288.59	-100.74	Yes
Day 34	2,562.11	-155.86	Yes	273.26	-110.80	Yes
Day 35	2,517.26	-168.33	Yes	265.12	-121.28	Yes
Day 36	2,535.90	-185.01	Yes	263.79	-146.19	Yes
Day 37	2,461.75	-176.20	Yes	261.08	-139.63	Yes
Day 38	2,443.16	-185.17	Yes	260.92	-156.28	Yes
Day 39	2,491.01	-152.25	Yes	262.88	-135.11	Yes
Day 40	2,451.53	-167.88	Yes	255.23	-149.35	Yes
Day 41	2,319.18	-184.13	Yes	244.44	-153.43	Yes
Day 42	2,395.00	-164.77	Yes	250.40	-120.27	Yes
Day 43	2,404.90	-170.29	Yes	250.27	-133.52	Yes
Day 44	2,355.10	-162.38	Yes	242.65	-126.36	Yes
Day 45	2,294.32	-171.97	Yes	237.22	-156.54	Yes
Day 46	2,339.30	-180.39	Yes	242.19	-140.55	Yes
Day 47	2,264.54	-209.57	Yes	235.26	-202.54	Yes
Day 48	2,318.31	-208.51	Yes	235.95	-190.51	Yes
Day 49	2,281.07	-172.35	Yes	235.77	-136.69	Yes

TABLE F.6

OBSERVED TEST STATISTIC SUMMARY FOR WEIGHT AND CUBIC FEET REQUIREMENTS (FH = 3.0, RST = 4.0)

20 Trial Runs	AVG Weight	T-Stat	Reject Ho	AVG Cubic Feet	T-Stat	Reject Ho
Day 20	20,766.59	-4.26	Yes	2,168.06	7.74	No
Day 21	16,424.47	-17.91	Yes	1,726.53	-5.18	Yes
Day 22	13,396.70	-26.85	Yes	1,413.34	-14.34	Yes
Day 23	11,184.21	-35.54	Yes	1,170.74	-23.38	Yes
Day 24	9,134.98	-51.51	Yes	958.48	-34.27	Yes
Day 25	7,646.01	-61.31	Yes	803.86	-43.80	Yes
Day 26	6,580.07	-56.17	Yes	689.75	-43.41	Yes
Day 27	5,755.93	-70.52	Yes	604.09	-52.99	Yes
Day 28	4,980.58	-68.69	Yes	522.48	-53.38	Yes
Day 29	4,408.76	-82.23	Yes	459.38	-67.55	Yes
Day 30	4,003.20	-95.10	Yes	412.72	-82.46	Yes
Day 31	3,825.16	-97.99	Yes	393.34	-86.49	Yes
Day 32	3,591.08	-125.99	Yes	367.93	-98.49	Yes
Day 33	3,484.36	-108.32	Yes	363.07	-92.87	Yes
Day 34	3,371.64	-117.55	Yes	349.68	-94.86	Yes
Day 35	3,252.01	-125.92	Yes	333.92	-118.06	Yes
Day 36	3,070.22	-130.11	Yes	316.17	-121.21	Yes
Day 37	3,088.16	-124.19	Yes	315.49	-119.54	Yes
Day 38	2,919.14	-114.91	Yes	302.36	-94.14	Yes
Day 39	2,870.44	-137.35	Yes	299.05	-99.70	Yes
Day 40	2,818.66	-130.13	Yes	294.84	-95.36	Yes
Day 41	2,708.21	-145.19	Yes	284.75	-107.66	Yes
Day 42	2,678.85	-135.53	Yes	283.10	-106.03	Yes
Day 43	2,571.74	-119.35	Yes	273.51	-92.76	Yes
Day 44	2,628.71	-145.62	Yes	271.96	-121.48	Yes
Day 45	2,677.74	-168.31	Yes	278.64	-129.48	Yes
Day 46	2,834.66	-130.27	Yes	291.70	-100.90	Yes
Day 47	2,831.46	-196.90	Yes	292.97	-145.64	Yes
Day 48	2,640.77	-173.39	Yes	274.85	-131.43	Yes
Day 49	2,678.51	-158.62	Yes	279.82	-123.69	Yes

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Bollinger Vita

Captain Jennifer A. Bollinger was born on 17 March 1965 in Tyrone, Pennsylvania. She graduated from Tyrone High School in 1983 and attended the Pennsylvania State University in State College, Pennsylvania. She entered Penn State University in August 1983, and graduated with a Bachelor of Science degree in Aerospace Engineering in January 1988. She received her commission on 28 January 1988 and entered the Air Force in October of that year. Upon graduation from Aircraft Maintenance Officer School at Chanute Air Force Base, Illinois in April of 1988, she was assigned to the 12th Flying Training Wing at Randolph Air Force Base, Texas.

In May 1992, she was assigned as an F-111 structural engineer in the Aircraft Maintenance Directorate at the Sacramento Air Logistics Center, McClellan Air Force Base, California. In May of 1993, she became the Director of Logistics in the 652nd Combat Logistics Support Squadron at the Sacramento Air Logistics Center.

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Upon graduation, she was assigned to the 6th Aerial Port Squadron, Howard AFB Panama. In May 1989, she was assigned to the 611th Aerial Port Squadron, Osan AB Republic of Korea, followed by an assignment in 1990 to the 313th Aerial Port Squadron, Royal Air Force Mildenhall, United Kingdom. While at RAF Mildenhall, she was selected to participate in the Logistics Officer Professional Development program and crossflowed to the Supply Officer career field.

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13. ABSTRACT *(Maximum 200 words)*

Lean Logistics was developed in response to budget cuts, force reductions, and a new political world order. The primary objective of Lean Logistics is to minimize the total system wide costs of the Air Force organization. Currently, the Air Force is seeking to cut costs by reducing inventories, improving repair processes, and employing faster transportation where possible. The purpose of this thesis is to determine if the Air Mobility Express (AMX) current sizing plan is capable of supporting the retrograde assets generated during the sustainment portion of a war. The Dyna-METRIC version 6.4 simulation program is employed to analyze the effect of varying such parameters as flying hours and retrograde shipment time on the weight and space required to move retrograde assets. Analysis of the results was accomplished using a Small Sample Test of Hypothesis. The results indicated that the current sizing plan is capable of handling the retrograde cargo generated by four F-16C squadrons for the six scenarios evaluated. This research also hints that while the current plan is capable of supporting four F-16C squadrons, it should be increased to support the transportation of reparables for all weapon systems involved in the war effort.

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